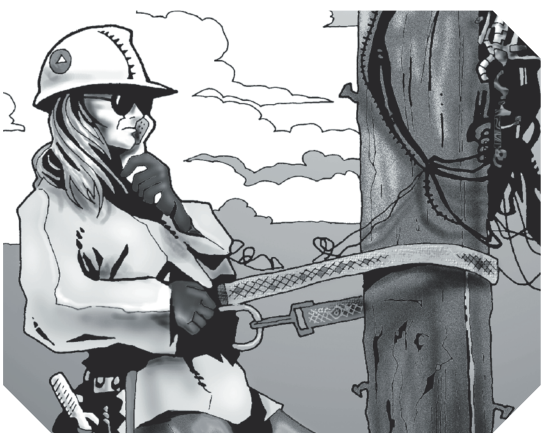
GURPS Fourth Edition

HIGH-TECH™

ELECTRICITY AND ELECTRONICS™



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CONTENTS

Additional Art Acknowledgments

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Introduction

*Jenkins fetched a collection of glass and metal contrivances he called "Leyden jars," which he said would promise us an **electrifying** evening. Miss Hathaway, ever the bold spirit, invited him to demonstrate, and at his instruction, placed her hand across two metal tabs that protruded, one from the inside and one from the outside. She jumped and nearly knocked the thing over, and pronounced the sensation most remarkable. At that, everyone would have their turn, and not wanting to seem timid, I took mine as well and felt as if a spark had leapt to my fingers on a hot, dry day. Then Miss Hathaway challenged Jenkins to partake of his own bottles, and he reached out a hand to one that remained undischarged – and fell across a chair. We feared he had hurt himself, but in a moment he stood up and pronounced the electric charge uncommonly strong, at which I told him that he must learn to measure the proof of the electric fluid when he bottled it. Much laughter, and I went away pleased for once to be the evening's **bright spark of wit,** as Miss Hathaway pronounced me.*

– ***GURPS Steam-Tech***

GURPS High-Tech: Electricity and Electronics is a supplement to ***GURPS High-Tech.*** It examines one of the characteristic features of the high-tech era (TL5-8) – the use and control of electricity – in greater depth. ***High-Tech*** provides statistics for basic devices, including large devices intended for stationary or vehicular use. This supplement builds on what's in ***High-Tech*** and provides more detailed or updated treatments of select equipment along with many new types of devices. The information in this book can help a campaign in several ways.

In the first place, ***Electricity and Electronics*** adds to the equipment presented in ***High-Tech*** or the ***Basic Set***. If you're playing a skilled technologist or a brilliant inventor, this supplement gives you more choices for equipment – or for devices you might invent a few years early! The emphasis is on portable devices that could fit into a backpack or the trunk of a car, and be taken along on adventures.

In the second place, the history of electrical technology is one of rapid change. New devices emerge all the time. In this book, you can learn when they came on the market, and equip characters with historically plausible gear for the Age of Steam or the Cold War.

In the third place, some of these innovations emerged in multiple forms. An inventor in a transitional period can have exotic experimental devices with distinctive advantages and disadvantages.

In the fourth place, this material looks ahead to the edge of TL9: to equipment that isn't yet commercially available, but that has been created in prototype versions. Rather than an inventor of yesterday, you can play one of today!

In addition to lists of gear, ***Electricity and Electronics*** provides *historical context:* the discovery of new scientific principles, their translation into new engineering designs, and their impact on society. It also expands and clarifies existing game mechanics: for electric power, for electric shock, for radio communication, for illumination levels, and various other topics. There's useful material for every phase of GMing, from creating a world to deciding what dice the players should roll.

About *GURPS*

Steve Jackson Games is committed to full support of ***GURPS*** players. We can be reached by email: **info@sjgames.com**. Our address is SJ Games, P.O. Box 18957, Austin, TX 78760. Resources include:

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Rules and statistics in this book are specifically for the ***GURPS Basic Set,*** *Fourth Edition.* Page references that begin with B refer to that book, not this one.

About the Author

William H. Stoddard is a professional copy editor, specializing in scientific and scholarly publications. He and his wife live in Riverside, California, with their cat Macavity, three computers, and more than 100 shelf-feet of books. He has been a roleplaying gamer since 1975, and has been writing for ***GURPS*** since 2000, when he composed ***GURPS Steampunk*** – which itself had a fair bit of information on electrical devices!

Chapter One
Basic Science

Technologies based on electricity were one of the major innovations of TL5. Inventors such as Franklin, Edison, and Tesla became legends, and many of them worked with electricity. It became a source of new devices, new skills . . . and new dangers.

The Progress of Science

For most of history, technology came before the science that explained it. Men threw rocks or fired cannon before Newton made ballistics a science; Carnot's theory of heat engines was based on the steam engines of Newcomen and Watt. Science might improve technology, but didn't create it. But in the 1700s, scientific study of natural phenomena began to suggest ways to turn them to practical use. Electricity was one of the first scientific fields to inspire useful inventions.

The Discovery of Electricity

The word "electricity" derives from the Greek word for amber, *elektron*. Greek natural philosophers knew that amber rubbed with cat fur attracted light objects such as feathers. The ancient world also knew of electric fish, which were sometimes used to treat various forms of pain (***GURPS Low-Tech,*** p. 153). In 1743, Benjamin Franklin brought together centuries of scattered observations with his theory about positive and negative charges, and he showed that lightning was a form of electricity.

In 1791, Luigi Galvani discovered that touching a dead frog's leg with connected pieces of different metals made it jerk. Alessandro Volta showed that immersing the same metals in acid produced an electric current; he invented the electric battery in 1800. Having a source of steady currents led experimenters to new advances.

For by stroking of his fur I have found out electricity.

– Christopher Smart, ***Jubilate Agno***

Electromagnetism

Among these advances was the discovery that electricity and magnetism interacted. Electric currents produced magnetic fields, and changing magnetic fields produced electric currents. James Clerk Maxwell published a unified mathematical theory of *electromagnetism* in 1873.

Maxwell's theory implied that changing electric and magnetic fields could propagate through space at the speed of light – and that light was electromagnetic radiation. In 1886, Heinrich Hertz demonstrated the production of *electromagnetic waves* with an apparatus based on a spark gap (p. 10) – the first radio transmitter.

From Science to Technology

Both electricity and electromagnetism started out as laboratory curiosities. Voltaic piles, electromagnets, the Edison effect (p. 5), and radio waves might be amazing, but no one expected them to be useful – often not even their discoverers. Nonetheless, the discoverers inspired inventors, who came up with ingenious devices that made it not just intellectually interesting but useful, often within the discoverer's lifetime. By the 20th century, organizations such as Bell Laboratories were systematically funding scientific research, confident that eventually it would pay off.

The Invention of Electronics

Electricity and electronics are distinct technologies and branches of engineering, though closely related. *Electrical engineering* applies electric power through various appliances and controls it with mechanical devices such as switches and relays. *Electronic engineering* is based on *active devices* that use electricity itself to control electricity. A major application of such devices was radio, and the field was called *radio engineering* until after World War II. Several classes of active devices have emerged over the history of the field.

Vacuum Tubes

The beginning of electronics came in 1906 with Lee de Forest's creation of the *triode*, which had an additional element – the *grid* – between the filament and plate of a vacuum-tube diode (see *Who Invented Vacuum Tubes?,* below). A weak signal at the grid could increase or decrease the flow of a larger current, like a valve in a water pipe (hence the British name "valve"). After World War I, a variety of more complex vacuum tubes were invented.

Transistors

In 1874, Karl Ferdinand Braun discovered that a thin wire touching a galena crystal would conduct electricity, but only in one direction. This became the basis for the "cat's whisker" detectors (see *Crystal-Based,* p. 28) in early radio receivers. In 1947, researchers at Bell Laboratories showed that a germanium crystal with *two* electrodes touching it could amplify signals, like a triode. The resulting active device, the *transistor,* came on the market in 1954. Over the next decade, the transistor largely replaced the vacuum tube. Over time, single transistors gave way to *integrated circuits* with hundreds, thousands, or millions of transistors on a single chip (*Miniaturization,* p. 6).

Masers and Lasers

In 1953, researchers at Columbia University invented a new type of amplifier, based on Einstein's concept of "stimulated emission." Rather than electric currents, it amplified electromagnetic radiation directly, with incoming radiation triggering the release of more radiation. The original device worked at microwave frequencies and was named a *maser* (for *m*icrowave *a*mplification by *s*timulated *e*mission of *r*adiation). The same principle was applied to visible light in 1957, resulting in the *laser* (the first letter stands for *l*ight). Masers and lasers emit radiation at precise frequencies, with low noise, in beams that spread out extremely slowly, known as *coherent radiation.*

Masers and lasers didn't replace solid-state electronics (as it had previously replaced tubes), but by the start of TL8, they were in widespread use.

Who Invented Vacuum Tubes?

The late 19th century saw the discovery of the "Edison effect": If a metal plate was placed inside a light bulb, current from a battery flowed between the bulb's filament and the plate – but only when the battery's negative terminal was connected to the filament. In 1904, while working for Marconi, John Fleming discovered that the Edison effect could be used in a more sensitive detector for radio waves. However, his "diode," with only a filament and plate, had no amplifying function. Lee de Forest's triode, the "audion" (invented in 1906) could amplify signals, but contained traces of gas and tended to produce distortion (-2 to Electronics Operation rolls to process signals). In 1915, General Electric brought Irving Langmuir's hard-vacuum triode onto the market, overcoming these problems. De Forest and AT&T's lawsuit took away their patent, but their design was the basis of most future vacuum tubes.

Technologies

Beyond the difference between electricity and electronics, several other distinctions will come up in later chapters.

Energy and Information

It takes energy to make electric currents flow, and they can transfer that energy to the things they flow through. But turning a current on and off, reversing its direction, or changing its intensity can also carry information. Electricity performs both functions in different devices.

Using electrical energy to do work is commonly achieved by electrical engineering, but a microwave oven (p. 21), which does the work of heating things, is based on a magnetron, a type of vacuum tube (see above). Carrying messages is usually done electronically; but the telegraph (p. 26), telephone (pp. 26-27), and even early spark-gap radios (pp. 38-39), contained no active devices and were purely electrical. This book divides devices up primarily by what they do, not how.

Storage and Flow

Electrons can be held in one place, as a *charge,* or moved from one place to another, as a *current.* Current is measured as a rate of charge transfer over time. Similarly, an electrically charged system, such as a capacitor, contains *energy*; but if the charge is allowed to flow, it can do work, and the rate of work over time is *power*. This distinction between storage and flow is basic to electrical and electronic devices.

Wired and Wireless

The first electrical communication devices sent messages over wires, carried by electric currents. In the later 19th century, inventors looked for a way to send messages without wires. Eventually, devices based on Maxwell's electromagnetic equations (see p. 4) made this possible.

Near and Far Fields

Maxwell's equations actually predict more than one type of wireless effect. Far from a source (such as an antenna), electromagnetic radiation (such as radio waves) carries energy or information through *far-field effects.* But at close range, electric or magnetic fields have their own separate effects, which fall off with distance faster than radiation. These *near-field effects* can alter the functioning of the source, through processes such as body capacitance. Despite limited range, they have their own specialized uses.

Miniaturization

Over time, electronic devices have gotten smaller. De Forest's audion (*Who Invented Vacuum Tubes?,* p. 5) was about as large as a light bulb (SM -7). It was followed in 1938 by the all-glass miniature tube (SM -8) and in 1939 by the subminiature tube (SM -9), used in military equipment and hearing aids. The invention of the transistor in 1947 allowed a big jump downward (SM -11).

Integrated circuits, developed in 1958, started out with two to five transistors as regions of a single block of germanium (later silicon). Integration progressed through medium-scale integration (MSI; up to 500 transistors per chip) in 1968, large-scale integration (LSI; up to 20,000) in 1971, and very large-scale integration (VLSI; up to 1 million) in 1980, at the start of TL8. After this limit was exceeded in 1984, designers stopped coining new acronyms, but the trend continued. It inspired *Moore's Law,* the prediction (in 1965) that transistor density would double every two years. Research in nanoelectronics has begun to produce devices on the scale of viruses, in which quantum effects play a significant role.

Game Effects

Smaller devices weigh less and consume less power. Signals take less time to travel through them, allowing faster switching cycles (for computers) or response times (for analog circuits). They're also easier to conceal! However, integrated circuits can't be modified or repaired; Electronics Repair on these devices typically means removing and replacing an entire chip.

Analog and Digital

Early electronic devices were *analog:* They carried information in the form of varying currents, or changes in a radio wave's amplitude or frequency. The invention of computers required creating circuits that were either on or off, and storing information as on and off values – a *digital* form. At TL8, analog-to-digital and digital-to-analog converters became common, letting computers interface with the external world more effectively. A similar distinction applies to control systems (see *Electrical Control,* pp. 24-25, and *Digital Interfaces,* pp. 39-41): At TL8, many devices are controlled by keyboards or touch screens rather than dials and buttons.

Skills

A number of existing skills apply to electrical and electronic devices. For some of them, new specialties are available.

Electrician

see p. B189

This is the skill of building, maintaining, and repairing systems that generate, store, or transmit electrical energy. It does not include all devices that are technically "electrical": see *Electronics Operation* (below) and *Mechanic* (p. 7).

> *Basically, microchips are merely a technical improvement over clay tablets.*
>
> *– Florian Coulmas,* ***The Writing Systems of the World***

Electronics Operation

see p. B189

This is the skill of using electronic equipment. In this supplement, the following specialties are relevant: Communications (Comm), Electronic Warfare (EW), Media, Medical, Scientific, Security, Sensors, Sonar, and Surveillance. Other specialties involve technology based on superscience, which this book does not cover (see pp. B513-514).

Electronics Operation (Media) defaults to Photography-5 for editing visual images. Electronics Operation (Medical) defaults to Diagnosis-2. Electronics Operation (Scientific) defaults to a relevant science at -2 – as does Electronics Operation (Sensors or Sonar) for scientific applications. Electronics Operation (Security) defaults to Traps-2.

For ***GURPS*** purposes, "electronics" includes some devices that are technically *electrical* rather than *electronic* (*The Invention of Electronics,* pp. 4-5). For example, Comm includes the telegraph and telephone, invented before electronics was thought of; at TL5-7, it includes sending and receiving Morse code.

The following variant of this skill is available for non-electronic devices.

Machine Operation: The skill of operating a class of devices whose primary function is not electronic, and which aren't already covered by vehicle skills, weapon skills, or other specialized skills such as Photography. Some examples include industrial water pumps, mechanical analog computers, and printing presses. Depending on the type of device, the skill defaults to Electrician-5 or Mechanic (same)-5, as well as to Engineer (Electrical)-5 or Engineer (same)-5.

Electronics Repair (ER)

see p. B190

This is the skill of identifying and repairing problems with electronic equipment. In this supplement, it has the same specialties as Electronics Operation, plus Computers.

Engineer

see pp. B190-191

This is the skill of designing and building new devices and systems. The main specialties in this book are Electrical and Electronics; they apply respectively to devices covered by Electrician and by Electronics Repair.

Hobby Skill

see p. B200

Several IQ-based Hobby Skills involve electrical or electronic devices. Examples include model railroading (after Lionel Corporation released the first electric model trains in 1900) and amateur radio (which became an organized hobby in 1909) at TL6; high fidelity (based on World War II advances in electronics) at TL7; and computers, beginning a few years before TL8. Hobby Skills can substitute for operation or repair skills, but only for small, low-power systems.

A new IQ-based Hobby Skill is *Feats of Science*, based on practical knowledge of experiments and demonstrations that illustrate scientific principles in a visually dramatic or surprising way, similar to Feats of Strength (***GURPS Martial Arts,*** p. 57). Given a room full of the right equipment, you can roll to keep intelligent non-scientists entertained for an hour or two with electrical sparks, startling mechanical operations, and trivial explosions. New effects are at -4 for lack of familiarity. You have a basic working knowledge of the current state of the physical sciences, though it isn't terribly deep; you can roll to answer simple questions of fact (or current belief) that someone with an actual relevant scientific skill would get +6 or more to answer. At TL 7 and up, specialized variants become common; for example, "coilers" show off spectacular electrical displays from Tesla coils.

Mechanic

see p. B207

Maintenance and repair of some electrical devices involves specialties of Mechanic, either by device type, such as Analog Computers or Robotics, or by power-plant type, such as Electric Motor.

Musical Instrument

see p. B211

GURPS Low-Tech Companion 1: Philosophers and Kings, pp. 17-19, lists required specialties for this skill, based on how an instrument is played. Electronics offers some new specialties, which fall into the new broad category of *electrophones*, based on the interface that controls the electronic circuits.

Stylophone: Played by touching a conductive stylus to a grid of contacts that complete circuits. *Example:* stylophone. *Defaults:* Dulcimer, Mbira, and Tuned Percussion at -4; Keyboard at -5.

Theremin: Played by moving the hands near antennas to control circuits through body capacitance. *Examples:* ondes Martenot, theremin. The ondes Martenot also has a keyboard that is played with Musical Instrument (Keyboard). *Default:* Trautonium at -4.

Trautonium: Played by pressing a resistive wire to a conductive plate with a finger. *Example:* Trautonium. *Defaults:* Fiddle and Rebab at -3; Theremin at -4.

Photography

see p. B213

Used to capture images with any camera (analog or digital) and to process them with darkroom or image-editing software. Unfamiliarity penalties apply to using a digital camera after experience with analog, or vice versa. Photography defaults to Electronics Operation (Media)-5.

Physics

see p. B213

Physics includes the scientific study of electricity. At TL6+, one of its optional specialties is *electromagnetism,* which studies electric and magnetic fields and electromagnetic radiation. Physics (Electromagnetism) can substitute for any Physics roll in this supplement. Roll against Physics to detect and measure electromagnetic effects, to produce them in the laboratory, and to create and use experimental apparatus (pp. 10-12). Physics can substitute for Engineer (Electrical or Electronic) to invent new devices, but these are "proof of concept" designs that cannot be put into production. Setting up a production line requires a prototype created with an Engineer roll.

Understanding the Devices

Equipment listings in chapters 2-6 include the following information.

TL (Tech Level), Dates

Each device's tech level appears in parentheses after its name; for example, "Gold Leaf Electroscope (TL5)." This is the TL at which the item is produced for the market, with a little flexibility; if a device came out *just* before the next TL and remained in use for some time, it may be assigned to the later TL. Later-TL versions of a device – and sometimes later versions at the same TL – can have radically different capabilities.

Example: The first commercial cell phone was 10" long, weighed 1.75 lbs., cost $4,000, and only made analog phone calls; current smartphones are pocket-sized computers costing less than $1,000 – but both are TL8!

Because of this rapid change, the year of market availability is listed for some devices; this year is never listed in brackets. If no year is given for a higher-TL version of a device, assume it becomes available at the start of the new TL.

Breakable!

Some devices have components more fragile than their Hit Points indicate, such as light bulbs or vacuum tubes. If they're dropped or thrown, the components may break. A variation of the whiplash rules (p. B432) can determine this. Estimate the speed at impact, work out falling damage (p. B431), and apply it to the fragile components. Disregard the electronic device's DR in this calculation.

Example: When the police raid Big Louie's speakeasy, the radio gets knocked off the table. It weighs 8 lbs. and has 8 HP; since the floor is hardwood, this is doubled to 16 HP. Multiplying by velocity 5 for a 1-yard fall and dividing by 100 gives 0.80, for damage 1d-1. Rolled damage is 2 points. Each tube has negligible weight and 1 HP; "whiplash" reduces them to -1×HP, requiring HT rolls to survive. Three of the five tubes fail the roll and break. With DR 2, the radio as a whole suffers no damage; it will work without repairs – once the broken tubes are replaced!

Prototypes

In a high-tech setting, inventors can be heroic or even legendary figures, and players may want their characters to carry off inventive feats. The later chapters of this book support that goal.

Some listed devices are *prototypes* – working versions have been made, but aren't commercially available, and no market price has been established. Such devices are assigned *complexity* ratings, which can be used to assign a cost for building such a device (pp. B473-474). The year for a prototype device, provided in [brackets], is the year when a working model was first created. Other characteristics of a prototype are speculative, and aren't given specific values; they can be assigned to fit the assumptions of a particular campaign.

For many devices, the year the prototype was created is given in addition to the year the item came onto the market.

Example: The tungsten filament bulb (p. 21) is dated [1906] 1911 – the first one was made in 1906, and General Electric started selling them in 1911.

An inventive hero could imitate the prototype (*Production,* p. B474), reinvent it based on the concept (*Prototype,* pp. B473-474), or even create a device before the historical inventor.

Cost

The cost of a device is the price to buy it new. Used devices may be available for less, from 50% to 80% for recent models down to 10% or less for older ones that still work. Prices for earlier TLs are given in dollars circa 2004 (as in the ***GURPS Basic Set***), not in currency of the period (for example, a dollar in 1920 had the purchasing power of $9.40 as of 2004). Cost includes batteries if they're permanently built in, but not if the user is expected to replace them (*Secondary Batteries,* p. 18).

Cutting Edge

Newly developed devices commonly sell at high prices, well above the "retail price" (p. B474) that's listed as the device's cost. The same is true for new versions of existing devices with higher-end capabilities; for example, FM radio (see *Audio Transmission and Reception,* p. 32) started out as the domain of audiophiles. To represent this, treat them as priced one quality grade higher (see p. B345): basic quality is 5× cost and good quality is 20× cost; fine quality isn't normally available. Some new technologies are explicitly called out as cutting edge, but this guideline can be applied to any device that's just past the prototype stage.

Weight

Weights of devices are given in pounds, down to 0.1 lb. Smaller devices are described as "negligible" ("neg."), with five to 12 negligible-weight devices adding up to a quarter pound. Weight includes batteries, if applicable. Larger devices, too heavy to be carried, are usually labeled "stationary," though they may be transportable in large vehicles such as trucks or ships.

Power

Rather than accounting for the exact power consumed by a device, ***High-Tech,*** pp. 13-15, defines standard categories of power availability. This book takes the same approach, with slightly more detail.

Rechargeable batteries (*Secondary Batteries,* p. 18) are often built into devices and not intended to be replaced. Such devices are listed as "rechargeable" with a duration.

For what ***High-Tech*** describes as *external power,* this supplement distinguishes five categories.

Peripheral Power (TL8). Supplies a small amount of power to an external device connected to a computer, letting it operate without an internal power supply. The universal serial bus (USB), an industry standard for peripherals since 1996, supplies five volts. With the increased prevalence of digital devices, USB ports are often built into automobiles and power outlets.

Automotive Power (TL6). An outlet provides access to a car's generator or battery; originally designed to power a cigarette lighter (p. 21). Supplies six volts (at TL6) or 12 volts (at TL7-8).

Household Power (TL6). Used for ordinary appliances, from lamps to desktop computers. Supplies 110-120 volts in North America and Japan; 220-240 volts elsewhere.

Major Appliance Power (TL6). Used for large appliances such as electric stoves, or for home workshops with large power tools. Supplies 230-240 volts.

Industrial Power (TL6). Used for heavy-duty equipment – for example, in a factory or on a warship. Typically supplies 480 volts.

HP, HT, DR

HP: A device's HP are determined by its weight, using the "Unliving/Machine" column in the table on p. B558. Devices with "negligible" weight have 1 HP. In a few cases, HP are stated explicitly.

HT: If not stated otherwise, a device has HT 10.

DR: Most devices have DR 2, unless a higher DR is specified. Fragile devices such as light bulbs or vacuum tubes can be assumed to have DR 0.

Electrical Hazards

With the development of generators and power lines, the dangers of electricity became widely known, helped by Edison's campaign against alternating current (*The Battle of the Currents,* p. 19). Different types of current produce different forms and levels of injury (pp. B432-433).

The rules for *lethal electrical damage* mainly reflect continuing current flows, such as from power lines (*Transmission,* pp. 18-19). They best fit the effects of direct current (DC). For DC, the HT roll to avoid heart stoppage is at -1 per 2 points of rolled damage; for alternating current (AC), -5 per 2 points; for radio-frequency current (as from a Tesla coil; see p. 12), disregard the effect. Any current that causes more than 1 point of injury prevents letting go of the source. Someone who makes a DX roll after touching a source that inflicts only 1 point can jerk back and avoid taking that injury.

Shocks from household current don't necessarily cause burns. To reflect this, as an optional rule, damage rolls less than 1d (see table under *Transmission,* p. 18) can inflict 0 burning damage, like a weak crushing attack. However, they may still trigger a HT roll, if the current passes through the torso. If the actual roll comes to 0, this is unmodified; if it's less than zero, treat the negative damage as giving a *bonus* to HT.

Nonlethal electrical damage comes from sources with high voltage but low current: static charges or capacitors (pp. 17-18) that discharge in a fraction of a second, or pulsed sources such as electric stunners (p. 49). The current is actually high, but the *average* current over a second or more is low (see *Storage and Flow,* p. 5). A discharge with high enough energy (-5 or more to the HT roll for stun) can cause a heart attack if the modified HT roll fails by 10 or more, or on a critical failure.

Lethal current may ignite fires, if it creates sparks or flows through resistive material; treat the rolled damage as a fire source (*Making Things Burn,* p. B433). Sparks from nonlethal damage may ignite Super-Flammable materials; roll 3d vs. (12 minus the HT modifier) for the shock to see if this happens. For example, roll 3d against 7 if the HT modifier is +5, or against 16 if it's -4).

At industrial or higher voltages, *arc flash* can occur, producing heat enough to melt metal or start fires (3d burn damage for 1 second) and dazzling light (treat as 1,000,000 lux for -1 to HT; *Light Levels,* p. 20). If the eyes aren't protected against ultraviolet with welder's goggles, roll vs. HT as for crippling injuries (pp. B422-B423) to see if visual impairment is lasting or permanent.

Lightning is technically a static discharge, but releases enough energy to cause lethal electrical damage or ignite fires. A typical lightning bolt causes 6d burn damage. It's less lethal than this suggests; roll vs. HT to check for heart failure, but at -1 per 5 points of injury. Larger bolts are possible; multiply the damage from a large bolt by 1d-2 (minimum ×1). Lightning rods (p. 15) protect buildings against such damage; a Faraday suit (p. 15) protects an individual wearer.

Combined Devices

For some equipment, early versions had to be combined with other devices (such as a display device) in order to get the most benefit from them. (Popular combinations were often later manufactured as a single unit.) Such a *combined device* is fussier to operate (-2 to the relevant skill). The penalty is less severe than for improvised equipment (-5 for technological skills; p. B345), because the components are *designed* to be used together; it's just a question of setting them up properly.

Chapter Two

Laboratories and Workshops

People who work with electricity use special tools and devices. This chapter examines the equipment needed for laboratory work (on electrical phenomena and in other branches of science and medicine) and for maintaining and repairing electrical and electronic devices.

For details about terms used in equipment descriptions, see *Understanding the Devices,* pp. 8-9.

Experimental Apparatus

Progress in electricity and electronics begins in the laboratory. Over the past three centuries, experimental physicists have developed a variety of devices for working with electrical phenomena. Except as otherwise noted, roll vs. Physics or Electronics Operation (Scientific) to use them.

Spark Gaps

Air at sea level has *dielectric strength* 76,000 volts per inch. If two electrodes are brought together, the distance at which a spark forms indicates the voltage difference. Roll vs. Physics at -5 to improvise a voltage-measurement device with a spark gap.

Detection and Measurement

Electrical experimenters have various devices for detecting and measuring electricity and electrical phenomena.

For *detection,* a successful roll indicates that a charge, current, or signal is present. Roll at +4 to detect a voltage high enough to cause damage (*Electrical Hazards,* p. 9); routine professional use succeeds automatically, except on a failed monthly job roll. For weak sources, roll at -4. Instruments become more sensitive with advancing technology, eliminating penalties for weak sources and making even weaker ones detectable.

Measurement can be carried out either for its own sake, or as part of a larger project. In the former case, a successful roll obtains an exact value. On a failed roll, the measurement is in error by ±5% × the margin of failure. On a critical failure, the instrument stops working or produces an absurd result. Quality (p. B345) allows more precise measurement: ±1% for good-quality equipment, and ±0.25% for fine-quality equipment. Quality also gives the standard bonuses to effective skill, and improvised devices give the standard penalty. For larger projects, quality of instruments is one factor in the quality of an entire tool kit (pp. 14-15).

Electrometers

The oldest device for electrical measurement, an electrometer indicates the presence of electric charge. This can warn against potential electrical damage, lethal or nonlethal.

Gold Leaf Electroscope (TL5). An electric charge causes two pieces of gold foil suspended from a conductor to repel each other and separate. After being charged, it can be used for detecting radiation, which causes the charge to leak off; roll vs. Physics. $20, 0.5 lb. 1787.

Quadrant Electrometer (TL5). A device for detecting *and measuring* the voltage difference between two objects. A metal vane rotates at an angle proportional to the difference. Power comes from a Daniell cell (see *Wet Cell,* pp. 16-17) built into the meter. $340, 5 lbs. 1857.

Vacuum-Tube Electrometer (TL6). A specialized vacuum-tube voltmeter (p. 11) with an input resistance so high that almost no current flows when it's connected to charged bodies, leaving the charge nearly unchanged. Can be improvised from a standard voltmeter and resistors. Household current. $100, 10 lbs. 1930.

Solid-State Electrometer (TL7). A more compact device using transistors. 2×XS/120 hours or rechargeable/120 hours. $40, 1 lb. 1960.

Galvanometers and Related Devices

Based on the discovery that current in a wire could deflect a nearby compass needle, the galvanometer detects electric currents. A calibrated scale makes it the basis for ammeters, voltmeters, and other instruments.

Moving Magnet Galvanometer (TL5). Reveals the presence of electric current by the movement of a pointer. Can be improvised from a compass and a length of wire. Subject to disturbance by magnetic fields or ferrous metals – apply a penalty of -1 to -10. $110, 5 lbs. [1820] 1836.

Mirror Galvanometer (TL5). A tiny mirror that deflects a beam of light replaces the pointer, for greatly increased sensitivity (treat as cutting edge; see p. 8). Developed during the transatlantic cable project, it could be connected to a telegraph line to detect weak signals; roll vs. Electronics Operation (Comm)+4 to read messages. $550, 5 lbs. [1826] 1858.

D'Arsonval Moving Coil Galvanometer (TL6). As sensitive as the mirror galvanometer and unaffected by magnetic fields. $110, 4 lbs. 1880.

Strip Chart Recorder (TL6). Inspired by automatic recorders for telegraph messages; one or more galvanometers move pens up and down on a steadily moving paper strip. This records current or voltage from a source, as in an electrocardiograph (p. 12). Household current or M/6 hours. $280, 16 lbs. [1848] 1888.

Multimeter (TL6). Also known as a volt-ohm-milliammeter (VOM). Combines the functions of a voltmeter (which measures voltage), an ammeter (which measures current), and an ohmmeter (which measures resistance) – all invented and available separately after 1900. Can also be used with Electrician or Electronics Repair. XS/120 hours. $26, 4 lbs. Originally worked only for DC; from 1931 on, includes a rectifier that allows use with AC. 1923.

Vacuum-Tube Voltmeter (VTVM) (TL6). A voltmeter that amplifies weak signals and allows readings that are more accurate. Early models have poor stability (-2 to effective skill). Household power. $52, 10 lbs. [1922] 1936.

Field Effect Transistor Voltmeter (FET-VM) (TL7). A more compact device using transistors. 2×XS/120 hours or rechargeable/120 hours. $20, 1 lb. 1960.

Signal Generators and Tracers

Electronic circuits require diagnostic equipment that can determine what they're doing to the signals they amplify. A signal generator inputs a signal; a signal tracer detects whether it's still present at various stages, and if it's distorted. Roll vs. Electronics Repair to use.

Audio Signal Generator (TL7). Generates standard audio-frequency waveforms such as sine waves and square waves. Walt Disney Studios bought eight of the first models to test sound equipment used in filming *Fantasia.* Household power. $20, 10 lbs. 1938.

Radio Signal Generator (TL7). Generates modulated radio-frequency waveforms for testing radio circuits. Household power. $30, 10 lbs. 1938.

Signal Tracer (TL7). The complement to a signal generator. Probes connected to a circuit pick up the signal. The amplified signal is output to a small loudspeaker. Contains a crystal detector for radio-frequency signals; no modifier for audio or AM, but -5 to skill for FM. Modified for good or bad hearing. Household power. $30, 6 lbs. 1938.

Lock-In Amplifier (TL7). A sophisticated device that can tune to a signal at an exact frequency (within 1 hertz) and measure its intensity, despite interference; disregard penalties of up to -6 for electrical "noise." Can be used to synchronize two signals, making possible exact timing of measurements. Household power. $4,000; 25 lbs. [1941] 1962.

Lock-In Amplifier (TL8). A digital version that cancels up to -9 of interference penalties! Household power. $4,000; 25 lbs. 2000.

Waveform Analysis

Alternating current (see *High-Voltage Systems,* p. 19), and later analog electronics (see Chapter 4), made imaging current flow over time useful. Originally this was done by hand, using carefully timed meter readings to trace a repetitive waveform, such as from a generator; roll at -2 vs. Mathematics (Applied) or Physics to plot the curve accurately. Taking extra time (p. B346) can enhance effective skill. Waveform analysis devices perform the same task automatically.

Oscillograph (TL6). Traces waveforms of signals on a strip chart (above). A switching mechanism samples a repetitive waveform at intervals, tracing one small section at a time. Household current or M/6 hours. $340, 20 lbs. 1888.

High-Frequency Oscillograph (TL6). A later design with a mirror galvanometer (above) and photographic paper traces actual waveforms at frequencies of a few kilohertz. $360, 10 lbs. 1920.

Oscilloscope (TL6). Uses a cathode-ray tube (which scans an electron beam over a photoelectric screen) as a display device, with amplifiers. +1 to signal tracing (pp. 47-48). Electronics Operation (Scientific) allows analysis and comparison of signals; for example, it can determine if two voices are from the same person. Household power. $520, 18 lbs. [1899] 1931.

Spectrum Analyzer (TL7). A special-purpose variation on the oscilloscope, which shows relative energy at different frequencies in a signal. Usable as a signal tracer (p. 48) at +2 for both AM and FM signals and in electronic warfare (see *Signals Intelligence,* pp. 47-48, and *Jammers,* p. 49-50). Audio-frequency applications range from analyzing vibration patterns in machinery (+2 to Mechanics rolls to diagnose problems; requires an accelerometer, p. 13) to analyzing speech sounds (+2 to Linguistics; requires a microphone, p. 31). The device is equivalent to gaining Discriminatory Hearing (p. B49). Household power. $50,000, 30 lbs. [1957] 1960.

Digital Oscilloscope (TL8). Uses analog-to-digital conversion and can store and play back signals. Household power. $280, 7.5 lbs. 1980. A compact model is XS/4 hours. $150, 6 lbs. 1985.

Static Electricity

As early as 1663 (late TL4), electrical researchers worked on machines for accumulating static charges at high voltages. Roll vs. Hobby Skill (Feats of Science) or Physics to operate.

Wimshurst Generator (TL6). Two wheels holding multiple electrodes, rotating in opposite directions, accumulate charges in Leyden jars (p. 18) through electrostatic induction, starting from an initial small charge. $130, 10 lbs. 1883.

Van de Graaff Generator (TL6). A moving belt takes on charge outside a hollow sphere and deposits it in the interior, from which it moves to the surface. This small model, suited for classroom demonstrations, has a 9"-diameter sphere and can get up to 340,000 volts, with a charging time of 10 seconds. It comes with a discharge wand.

If not discharged, it can deliver a nonlethal shock to an uninsulated person (+2 to HT to resist; see *Electrical Hazards,* p. 9). Larger generators can be built, and they deliver stronger shocks (-6 to the HT roll for each ×2 diameter, or -3 for ×1.5). $260, 18 lbs. 1929.

Tesla Coils

Used in experiments with wireless power transmission (p. 19), for special effects in films, and to perform demonstrations at public events.

Tesla Coil (TL6). A source of high-frequency current that can jump wide air gaps, producing spectacular sparks. Roll vs. Electrician, Hobby Skill (Feats of Science), or Physics to construct and operate. The output causes 1d-3 burn on a critically failed operation roll; on an unmodified roll of 18, a spark may contact the power line (if unshielded), conducting low-frequency AC with potentially lethal effects (*Electrical Hazards,* p. 9). Average complexity. Major appliance or industrial power. [1891]. More recently, small Tesla coils have come on the market for teachers and hobbyists, producing comparatively low power (1 point burn). Household power. $150, 3.75 lbs. 1995.

Scientific and Medical Electronics

Electrical and electronic devices can be used in many scientific fields. Roll vs. Electronics Operation (Scientific or Medical) to operate them. Unusually complex devices impose penalties, from -1 to -5, which are doubled for rolls vs. the relevant science. Taking extra time (for example, to read the manual!) can compensate for these. Failure produces an inaccurate result (see p. 10). Roll vs. an appropriate science to interpret the results; computer programs may give bonuses.

Bioelectrical Signals

Galvani's discovery of bioelectricity (see p. 4) led to 19th-century studies of the electrical activity of living tissues, using galvanometers (pp. 10-11). In the 20th century, the electrical activity of the heart (electrocardiography, EKG; [1901] 1927) and brain (electroencephalography, EEG; [1924] 1938) could be traced with a strip chart recorder (p. 11), viewed on an oscilloscope (p. 11), or stored in a computer (pp. 36-380. Roll vs. Diagnosis to interpret the results. Readings were originally carried out using large stationary apparatus.

Heart Monitor (TL7). A small electrocardiograph, typically with only three electrodes, designed to transmit heart activity by radio to a recorder over a full day or more for diagnostic use (-2 to Diagnosis for briefer use, -4 for less than half an hour). 2×XS/1 year. $50, 0.25 lb. 1952.

Digital Heart Monitor (TL8). Can be used in physical training for HT or fitness, allowing exercise at an optimized rate that reduces training time by 10%. XS/12 hours. $100, 0.25 lb.

Wireless EEG Headset (TL8). A headset with multiple electrodes that reach through hair to contact the scalp, with an analog-to-digital converter for EEG readings, providing input to a computer (*Brain-Computer Interfaces,* p. 41). XS/12 hours. $600, 0.25 lb. 2009.

Transducers and Meters

A transducer converts one form of energy into another, such as an electrical signal. Each type of transducer can be combined with a display device – such as a galvanometer (pp. 10-11) or oscilloscope (p. 11) – with a roll vs. Electronics Operation (Scientific) or Electronics Repair (Scientific) at +2, or the appropriate science. A failed roll means the combined device produces no meaningful readings. A critical failure damages the transducer through clumsy handling or incorrect connection – roll vs. its HT to avoid destroying it; if it's not destroyed, roll vs. Electronics Repair (Scientific) to repair it. Most transducers are later integrated into dedicated special-purpose devices, which require no assembly; dates are given for these as well.

Roll vs. Electronics Operation (Scientific) +2 or the relevant science to operate a dedicated device; roll at -2 for a combined device (p. 9). The rules for detection and measurement (see p. 10) also apply. Roll at +4 to detect most hazardous conditions, such as concentrated acids or alkalis or radiation exposure.

Geiger-Müller Tube (TL6). Produces an electrical signal when exposed to radiation, with an automatic counter. Requires a high-voltage power supply that can inflict 5d lethal electrical damage; this can be built as a Simple complexity invention using household power. $50, 0.75 lbs. [1908] 1928. The standard tube is built into portable Geiger counters. 3×S/12 hours, $200, 2.5 lbs. 1928.

Glass Electrode (TL6). Measure a solution's acidity or alkalinity, described by pH. Pure water has pH 7; lower pH indicates acidity, and higher pH indicates alkalinity. 0.5 lb., $100. [1909] 1929. An integrated pH meter was developed in 1935. Household power. $960, 15 lbs.

Thermistor (TL6). A temperature sensor based on changes in the resistance of a material with temperature. $5, neg. [1833] 1930.

Metal Detector (TL6). A handheld device a yard long that generates an oscillating magnetic field that changes frequency in the presence of metal up to 6" deep for small objects such as coins, or 20" for large objects. Manual correction of frequency drift is needed, giving -2 to Electronics Operation rolls. Roll vs. Archaeology, Geology, Prospecting, or Scrounging to interpret rolls. 6×S/8 hours. $100, 12 lbs. [1925] 1931.

Photodetector (TL6). In early versions, a selenium-based photovoltaic cell generates a current when bright light shines on it, measuring the illumination level to the nearest step (see p. 20) on a roll vs. Electronics Operation (Scientific), at a penalty equal to the partial darkness penalty.

Integrated light meters avoid penalties to Photography for low or excess light. In 1935, they begin to be built into cameras. $28, 0.5 lb. [1879] 1932.

Accelerometer (TL7). Produces an electrical signal when accelerated, either by its own weight when resting on a surface (no response in free fall), or by being pushed, pulled, or vibrated. Came into widespread use in the World War II aviation industry. $15, 1 lb. [1923] 1939.

Light Meter (TL7). Works like the TL6 light meter, but silicon-based cells eliminate the partial darkness penalty. XS/12 hours, $60, 0.25 lb. 1970.

Metal Detector (TL7). Automatic correction of frequency drift eliminates the skill penalty. 6×S/8 hours. $100, 12 lbs. 1965. At TL8, halve the weight.

pH Meter (TL7). A compact model. S/12 hours, $700, 1 lb. 1956.

Accelerometer (TL8). The invention of MEMS (p. 24) made possible much smaller, cheaper, usually digital accelerometers implemented on chips. Since 2000, such chips have been incorporated into smartphones, tablets, and game controllers. T/120 days or rechargeable/120 days. $4, neg. 1993.

Digital Thermometer (TL8). Used with skills such as Chemistry (for laboratory work), Diagnosis (for medical thermometers), or Housekeeping (for food thermometers), normally without a skill roll. Each field requires specially designed thermometers to fit its temperature range and environmental conditions. T/2 years. $15, neg. 1980.

Electronic Pedometer (TL8). Based on an accelerometer chip. Usable for Navigation (Land) by dead reckoning or as an aid to training Hiking skill (-10% to required study time). T/1 month. $10, neg. 2000.

Geiger Counter (TL8). A smaller device with a digital display. 2×XS, $260, 1.25 lb. 1993.

Lab-on-a-Chip (TL8). A family of chemical and biological devices contained in integrated circuit chips, using MEMS (p. 24) to pump fluids and perform other mechanical processes. The first lab-on-a-chip was a gas chromatograph developed in 1979. Lab-on-a-chip systems can analyze extremely small samples of material, or single living cells, canceling penalties of up to -4 to Chemistry, Biology, or Diagnosis for small quantities. A few systems are Average, but most are Complex.

pH Meter (TL8). A smaller device with a digital display. 2×XS/24 hours, $375, 0.75 lb.

Transmission and Recording

Readings on scientific instruments can be transmitted to remote locales in the same ways as other signals (*Modes of Transmission*, pp. 26-30), a process called *telemetry*. Wire transmission began as early as 1845 and was common throughout TL6. Experimental radio telemetry from weather balloons began in 1920 (TL6); the *radiosonde,* which converted readings to Morse code, became standard after 1930. At TL7, more advanced coding systems were adopted, which could carry information even over interplanetary distances. Roll vs. Electronics Operation (Scientific) or Electronics Operation (Comm) to pick up usable signals.

So we go ahead,
And the meters
are over in the red.
– Kate Bush,
"Experiment IV"

Analog Computers

Before digital computers (pp. 36-41), complex mathematical problems were often solved by *analog computers,* which represented numbers as measurable physical processes (*Analog and Digital,* p. 6). Early analog computers were mechanical; electric motors were used as power sources after 1912. The high point of this technology was the *differential analyzer,* patented in 1936, which interconnected simpler analog devices to solve a variety of problems; it cost $200,000 and filled a room.

In ***GURPS*** terms, an analog computer is a modified copy of an invention, requiring a roll vs. Engineer (Analog Computers) to create. It has the cost of a single copy. Basic devices are Average inventions and typically fit on a desktop; the differential analyzer and comparable devices are Complex inventions as large as a megacomputer (p. 37). To "program" a prototype flexible analog computer, roll vs. Mathematics (Applied) to define the problem and vs. Mechanic (Analog Computers) or Electronics Repair (Scientific) to set up the machine.

Electrical networks came into use as analogs of physical systems after 1929; commercial models were available after 1950. The emergence of digital computers at TL7 relegated analog computers to specialized problems. By the mid-1970s, digital computers running simulation software became fast and powerful enough to replace them.

General-Purpose Analog Computer (TL7). A desktop model designed for easy reconfiguration; roll vs. Electronics Operation (Scientific). Solves scientific equations numerically within 0.1% accuracy. Household power. $30,000, 100 lbs. 1959. A larger model can solve systems of equations and run simulations. Household power. $150,000, 330 lbs. 1960.

Medical and Surgical Tools

Portable Diathermy Apparatus (TL6). D'Arsonval and Tesla independently showed that high-frequency currents didn't produce electric shock, but could warm living tissues. Shortwave diathermy uses this effect to relieve deep muscle pain or inflammation. After 30 minutes, roll vs. Physician to reduce the intensity of pain by one step (see p. B428 for definitions of steps). Early models, using Tesla coils and lower frequencies, give -2 to effective skill and can cause burns (1d-3) on a critical failure. Household current. $3,700, 15 lbs. [1890] 1920.

Electrocautery (TL6). Uses a heated wire to cauterize a small area of body tissue. Roll vs. Surgery to stop superficial bleeding (p. B420) or destroy small growths such as warts. Can also be used for Artist (Body Art). Normally used under local anesthesia, as the heat causes Severe Pain (p. B428). Major appliance power. $700, 10 lbs. 1925.

Autoclave (TL7). Sterilization at high pressure was discovered in Pasteur's laboratories. This electrically heated autoclave holds 25 quarts and provides sterile instruments for Surgery or Artist (Body Art). Household power. $550, 15 lbs. 1940.

Electroconvulsive Therapy Device (TL7). Experiments with electrical treatment of mental illness go back to the 1700s, but systematic use began shortly before World War II. A brief current through the brain triggers convulsions (treat as *Seizure*, p. B429); patients occasionally suffered broken limbs, but muscle relaxants avoided this after 1951. A course of treatments requires a roll vs. Physician, normally by a specialist in psychiatry. Successful treatment acts as a Mitigator for Chronic Depression or Manic-Depressive for 1 year. On a failed roll vs. HT-2, it produces quirk-level Amnesia affecting the 1d days immediately before its use; in a horror campaign, this may be beneficial! Household power. $3,700, stationary. [1938] 1940.

Defibrillator (TL7). Applies a brief high-voltage shock (effectively a very powerful nonlethal shock) to restore normal beating of the heart. Realistically, this treats ventricular fibrillation (random twitching of the heart, caused for example by lethal AC shock; see p. 9) but doesn't restart a stopped heart. Roll vs. Electronics Operation (Medical). On a success, the heart restarts on a roll vs. HT+1; this can be raised as high as HT+5 by repeated tries at higher energy, but is at -1 per 2 full minutes since fibrillation began. Early experiments applied current directly to the heart, requiring surgery to open the chest. Large stationary models allowing external application are available starting 1959. A portable version was developed later for paramedics. 2×XS/4 years. $900, 7 lbs. [1947] 1968.

Automated External Defibrillator (TL8). The automated external defibrillator (AED) provides effective Electronics Operation (Medical)-12 to users who can follow written instructions. 2×XS/4 years. $1,250, 5 lbs. 1978.

Cautery Pen (1991). A battery-operated device for cauterization. Disposable after use. XS/10 minutes. $10, 0.2 lb. 1991.

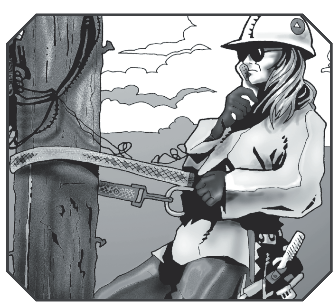
Digital Stethoscope (TL8). An electronically enhanced stethoscope giving +1 to hear faint sounds, canceling -1 to hearing from noise, and giving +1 to Diagnosis – or Lockpicking, for safecracking (see p. 42). Rechargeable/9 hours. $225, 0.5 lb. 2000.

Digital Thermometer (TL8). Described on p. 13.

Laser Scalpel (TL8). A laser-based cutting tool designed for surgical use. Very common in eye surgery. +2 to Surgery rolls that benefit from High Manual Dexterity. Different specialties of Surgery call for different designs. Household power. $1,850, 45 lbs. [1964] 1987.

Construction and Repair

After investigation of electrical phenomena come building, maintaining, and repairing electrical and electronic devices. Engineers and technicians have their own characteristic tools for tasks based on Electrician or Electronics Repair.



Hand Tools

Electricians and electronics technicians use a variety of hand tools. Handles are insulated against up to 1,000 volts (DR 18 vs. burn damage from lethal electric shock).

Lineman's Pliers (TL6). Heavy pliers shaped to be helpful in electrical tasks; basic equipment for Electrician. Gives +2 to activities that require a secure grip. Can be used as wire cutters. $13, 0.75 lb. 1890.

Needle Nose Pliers (TL6). Pliers with a long, pointed working surface able to reach into tight spaces. Cancels up to -2 in penalties for working in such environments. $11, neg. 1890.

Screwdrivers (TL6). A set of half a dozen screwdrivers for use with screws of varied types and sizes. Can be used to discharge capacitors safely (pp. 17-18). $37.50, 2.5 lbs. 1890.

Wire Cutters (TL6). A tool resembling pliers, with blades able to cut electric wire (2d(2) cut). Can be used to cut power lines (*Low-Voltage Systems,* p. 19). Substitutes for a wire stripper with a DX-based roll vs. Electrician or Electronics Repair. $9, neg. 1890.

Wire Stripper (TL6). A tool resembling pliers, having a pair of blades with a round notch. Used to cut through insulation on wires and pull it off. $15, 0.25 lb. 1890.

Soldering Iron (TL6). The iconic tool of the electronics technician or radio hobbyist, using resistance heating (*Resistive Elements,* p. 21) to heat a metal tip to 190°F or above. Inflicts 1 point burn per second. Household power. $100, 1.25 lb. 1894.

Soldering Iron (TL7). A smaller model of soldering iron. Household power. $12, 0.5 lb.

Antistatic Wrist Strap (TL8). The development of integrated circuits (p. 6) led to the discovery that many circuit boards failed to work after being handled, as a result of static discharge from human hands. The antistatic wrist strap protects against this problem, and against electric sparks igniting Super-Flammable materials (*Electrical Hazards,* p. 9). Must be grounded, using an attached cord ending in an alligator clip. Without this, failure by 2 or more under dry conditions, or critical failure under humid conditions, results in electrostatic discharge. $4, neg. [1975] 1980.

Soldering Laser (TL8). A soldering device using infrared light from a diode laser for extremely precise placement; +2 to DX-based rolls. Household power. $45, 10 lbs. 1980.

Tool Kits

Standardized tool kits are available for electricians after 1890, and for electronics technicians after 1912. For specifics on individual items in kits, see *Hand Tools,* above. A multi-tool (***High-Tech,*** p. 26) can be used as improvised equipment (-5 quality) for both skills. Tool kits come in three sizes.

Electrician's Tool Kits

Mini-Tool Kit. A belt-sized tool kit, which gives -2 (quality) to Electrician. A typical kit has screwdrivers, needle nose pliers, wire cutters, a test light, a penlight, electrical tape (cloth at TL6, vinyl at TL7-8; DR 10 vs. electricity), wire caps, and spare fuses (at TL6-7). $200, 4 lbs.

Portable Tool Kit. A kit that fits inside a standard toolbox. Allows unmodified skill rolls. Adds a tape measure, wire strippers, lineman's pliers, a multimeter, fish tape, a hammer, screwdrivers in varied sizes, lengths of color-coded wire, and varied small parts to the mini-tool kit. $600, 20 lbs.

Workshop. A large set of tools that fill a room, including materials and spare parts. Gives +2 (quality) to skill and -4 to rolls for Electronics Repair; $15,000, 2,000 lbs.

Electronics Repair Tool Kits

Mini-Tool Kit. A belt-sized tool kit, with screwdrivers, needle nose pliers, wire cutters, tiny through small batteries, wire in small sizes, electrical tape, and a few specialized tools and small parts; add a small soldering iron at TL7-8 and an anti-static wrist strap for Electronics Repair (Computers) at TL8. Gives -2 (quality) to one specialty of Electronics Repair. $400, 2 lbs.

Portable Tool Kit. A kit that fits inside a standard toolbox. Allows unmodified skill rolls for one specialty of Electronics Repair and gives -2 for other specialties. Adds a multimeter, test probes, a magnifying glass, a tape measure, a soldering iron (at TL6), and more small components to the mini-tool kit; each specialty has several distinctive tools and/or instruments, such as signal generators and tracers for Comm or Media at TL7. $1,200, 10 lbs.

Workshop. A large set of tools that fill a room, including materials and spare parts. Gives +2 (quality) to skill for one specialty of Electronics Repair, -2 to rolls for other specialties, and -4 to Electrician; $30,000, 500 lbs.

Safety Equipment

Electrical research and invention revealed the dangers inherent in electricity and lightning (*Electrical Hazards,* p. 9). A variety of equipment helps electricians and electronics technicians avoid them.

Lightning Rod

Franklin's demonstration that lightning was electrical (*The Discovery of Electricity,* p. 4) led to the *lightning rod* in 1749 (TL5). This provides a low-resistance path to ground, diverting the bolt from more vulnerable locations. TL5 lightning rods work on a roll of 14 or less; designs that take inductive effects into account (developed in 1888) work on a roll of 16 or less. On a failure, the structure *adjacent to* the lightning rod suffers half the rolled damage.

Protective Gear

Electrical Gloves (TL6). Gloves made of electrically nonconductive material. DR 1, flexible; against lethal electric shock, DR 25 (standard) or DR 75 (high-end). $35 (standard)/$135 (high-end); 1.2 lbs.

Hot Stick (TL6). A pole of nonconductive material on which tools can be mounted, making it possible to work on high-voltage systems such as power lines from a safe distance. A typical length is 1 yard, but hot sticks as long as 10 yards have been used. Tool use is at -2 to the relevant skill; this penalty can be bought off as a Hard technique. Early hot sticks, made of wood treated with wax or shellac, were used at up to 220,000 volts. $55, 1 lb. [1913] 1916. More recently, fiberglass hot sticks have been used at up to 750,000 volts. $130, 1.75 lbs. 1955.

Faraday Suit (TL7). Clothing with conductive wires or fibers woven in, worn by Tesla coil hobbyists and in bare-hand work on power lines at 220,000 volts or above. (For safe power-line work, the wearer must not be grounded; the suit is electrically connected to the power line.) Provides immunity to nonlethal electric shocks; DR 20 against burning damage from lightning and lethal electric shocks; blocks radio waves, including microwave area-denial attacks (see *Active Denial System,* p. 50). $1,500, 12 lbs. 1960.

Heathkits

After World War II, the Heath Company, a manufacturer of aircraft accessories, turned to a new line of products: buying surplus electronic parts and using them to create kits for home assembly, starting in 1947 with an oscilloscope. Kits came with highly regarded instruction sets for building and using them; many people became electronics hobbyists by working through a series of kits. The quality of completed devices was often competitive with that of factory-made equivalents.

Treat building a device from a kit as producing a single copy (p. B474). In addition to the 20% of retail price for parts, the detailed instructions add another 5%. However, they can be considered as equivalent to the One-Task Wonder perk for that one device (***GURPS Power-Ups 2: Perks,*** p. 17), allowing an IQ or Hobby Skill roll to build it. Time spent can give bonuses to effective skill (p. B346).

Home computers inspired a change of focus for many technical hobbyists, from building devices to writing programs; at the same time, the shift to integrated circuits (p. 6) reduced the cost savings from kits. In 1984, the Heathkit PC cost $100 *more* than a factory model and took 20 hours to assemble! Heath stopped selling kits in 1992. Other companies over the years have offered similar kits for many different kinds of electronic devices, with varying degrees of difficulty and customization.

Test Equipment

Several devices can be used to judge the risk of electric shock. Roll vs. Electrician+4 to detect unsafe conditions.

Insulation Resistance Tester (TL6). A specialized ohmmeter designed for measuring very high resistances (a widely used model is named the Wee Megger). Turning a hand crank produces DC test voltage between a conductor and the outside of its insulation. $130, 1.5 lbs. 1895.

Test Light (TL6). A device for determining if a wire or outlet is live. The end of one insulated lead is touched to a grounded surface, while the end of another is touched to the point being tested. A neon light glows if there's voltage. $6, neg.

Voltage Tester (TL7). A device for determining if a wire or outlet is live *without an electrical connection,* by capacitive coupling between the circuit and a probe tip, and between the user's body and ground. A small amplifier causes a light to glow if AC voltage is present. $20, neg.

Chapter Three

Power and Machinery

The starting point for practical devices is electrical energy. Energy is the capacity to do work; power is the rate at which work is done – so much energy per second (*Storage and Flow,* p. 5). At TL5 and TL6, electricity supplies power to an increasing range of useful devices. Repairing these devices usually calls for Electrician; operating them may be Machine Operation (p. 6). *Simple* devices are used with skills that fit a particular task, such as Housekeeping or Typing, or don't require any skill roll.

For a discussion of terms used in equipment descriptions, see *Understanding the Devices,* pp. 8-9.

Electrical Energy

A variety of sources provide electric power, either generating energy or storing it until it's needed. Power can be transmitted and distributed, allowing one big (and more efficient) power plant to support many machines.

Generation

Energy isn't created out of nothing. Devices that provide electric power do so by converting other forms of energy (such as mechanical or chemical energy) into electrical energy.

Primary Batteries and Fuel Cells

The first source of steady current flows was chemical reactions. What chemists call *reduction-oxidation reactions* transfer electrons from one molecule to another, releasing energy. With electrodes made of different materials immersed in a reactive solution (the *electrolyte*), electrons come from one electrode (the *anode*); flow through a circuit, doing work; and return to the other electrode (the *cathode*).

Primary Battery

Primary batteries get their energy from the chemicals they contain. When the chemical reaction is complete, they stop working. For rechargeable batteries, see *Secondary Batteries* (p. 18).

For simplicity, ***GURPS*** assumes that batteries come in standard sizes, defined by weight. This represents the weight of a TL7-8 *alkaline battery* of that size. Other battery types have different densities; if weight is important – for example, if the party carries a stock of extra batteries – the GM can apply the indicated modifier. Weights and costs for specific types are historically based alternatives to the generic rules in ***GURPS High-Tech.*** *Power requirements* are also stated in terms of alkaline batteries. Other types serve for shorter or longer times; lower-TL systems run out of power much faster. Most sizes became available at TL6; tiny batteries appeared at TL7.

Tiny (T). The size of a watch battery. $0.25, neg. 1957.

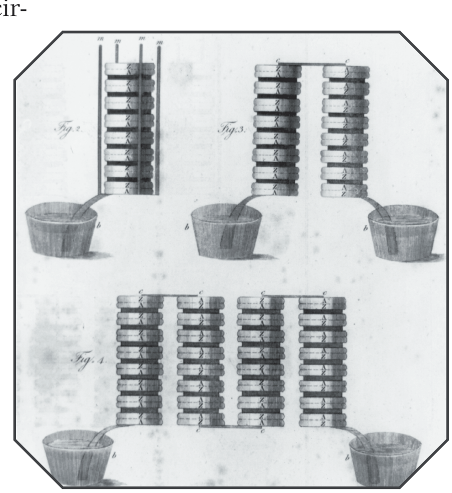
Extra-Small (XS). The size of a 9-volt battery or two AA batteries. $0.50, 0.1 lb.

Small (S). The size of a D battery (a typical flashlight battery). $1, 0.33 lb.

Medium (M). The size of a lantern battery. $5, 1.5 lbs.

Large (L). The size of a car battery. $15, 15 lbs.

Very Large (VL). A heavy-duty battery that can power a small vehicle such as a golf cart, or support devices such as radios for prolonged times. $30, 75 lbs.



Voltaic Pile (TL5). The original laboratory apparatus for supplying electric current. Roll vs. Chemistry or Physics to construct. Typical electrodes are copper and zinc. Roll vs. HT 10 after each 30 minutes of use; after a failed roll, the copper is covered with hydrogen bubbles, blocking current flow. It could have as many cells as needed for an experiment; the first arc light (p. 20) was powered by a 2,000-cell pile. Simple complexity. Stationary. [1800].

Wet Cell (TL5). The first source of current that functioned for prolonged times. It was the standard power source for telegraph stations until the 1950s.

The Daniell cell has a porous ceramic barrier between the electrodes, which weakens the current (-1 to Electrician or Electronics Operation). The gravity cell, with the zinc electrode above the copper one, provides a stronger current, but requires monitoring the solution. Roll daily vs. Electronics Operation (Comm) at TL5-7 or Chemistry to avoid loss of power; roll vs. Electronics Repair (Comm) at TL5-7 or Chemistry to set up a new cell, which provides power after 1 hour. Provides power one-fourth as long as a comparable-sized alkaline battery. Stationary. [1836] 1860.

Carbon-Zinc Battery (TL6). The first "dry cell," making possible portable devices such as the flashlight (p. 22). Provides power one-fourth as long as alkaline batteries; reduce weight and cost by 10%. [1866] 1896.

Alkaline Battery (TL7). A carbon-zinc battery with an alkaline electrolyte. [1900] 1959.

Fuel Cell

A battery where the oxidizing agent *is* oxygen, typically from the air, which reacts with a fuel, typically hydrogen. The electrodes are platinum-based catalysts that aren't used up. It works as long as it's supplied with fuel. Many fuel cells are stationary.

Fuel Cell Power Supply (TL7). An uninterruptible power supply providing major appliance power for one device, or household power for six to 10 devices. $6,250, 25 lbs. [1838] 1959. Fuel for 8 hours is 2.7 cubic feet of compressed hydrogen, weighing 6 lb. and costing $27. A composite tank to store it weighs 400 lbs., takes up 4.2 cubic feet, and costs $1,500. If stored oxygen is needed (in submarines or spacecraft), a tank half that size and cost can store 48 lbs. of compressed oxygen.

Generators

Generators convert mechanical energy into electrical with a conductor and a magnetic field in rotation relative to each other. Experimental designs date to 1831; practical models to 1866 for DC (the *dynamo*) and to 1887 for AC (the *alternator*). For an overview of hydroelectricity, see ***High-Tech,*** p. 15.

Human-Powered Generators

Adventurers may want to carry small generators that turn their own muscular effort into electric power.

Hand Crank Generator (TL6). A handheld generator that operates when a crank is turned; no FP are expended in doing so. Takes the place of one S battery, or recharges one XS battery in 1 hour or one S battery in 3 hours. May be built into a device such as a flashlight or emergency radio, instead of or in addition to batteries. $15, 0.25 lb. [1832] 1876.

Pedal Generator (TL6). A floor-mounted generator in which bicycle-type pedals turn a rotor. By expending 1 FP/hour, a person can take the place of two M batteries, or recharge one S battery in 1.5 hours or one M battery in 12 hours. $125, 50 lbs. 1929.

Wind Generators

Wind Generator (TL6). A generator driven by a wind turbine, mounted on a tower to provide clearance for the 8'-diameter blades. Adjusting its operation as wind changes calls for rolls vs. Machine Operation (Wind Generator); see p. 6. Power depends on wind speed: at high speeds, it supplies household power or can recharge a VL battery in 2 hours; at low speeds, it supplies automotive power or can recharge a VL battery in 10 hours. If there's no wind, it provides no power! $1,100, 100 lbs. (tower cost and weight excluded). [1887] 1930.

Wind Generator (TL8). More efficient turbines supply twice the output, use lighter materials, and operate automatically. $1,100, 50 lbs. 1980.

Photovoltaic Systems

Photovoltaic materials (discovered in 1839) produce electric current when exposed to light. The first practical solar batteries, produced in 1954, were used mainly in spacecraft; increasing efficiency led to light-powered wristwatches in 1968 and calculators in 1978. At TL8, such small devices cost no more than devices powered by T cells, and much higher efficiency makes solar energy usable in higher-powered systems. For TL7 solar panels, see ***High-Tech,*** p. 15.

Portable Solar Panel (TL8). A compact, foldable solar panel, the size of a briefcase when carried; folds out to a yard on a side. Equivalent to automotive power or three M batteries; can recharge an M battery in an hour or an L battery in a day. $150, 25 lbs. 2000.

Storage

Electrical energy can be stored, as well as generated. This can be useful for a variety of reasons. Power sources may not work all the time (as with solar energy) or may fail unexpectedly. It may not be convenient to keep a device connected to a power source. Storage devices provide extra power for times of high demand, or accumulate it for big surges, as in weapon systems.

The vital questions about storage devices are *how much* energy they store and *how fast* they deliver it. These determine how long they can supply power.

Capacitors

A capacitor ("condenser" until after World War II) stores a charge on two plates, one positive and one negative. If the plates are connected by an electric circuit, these neutralize each other almost instantly – a single surge, rather than sustained power. This can cause nonlethal electrical damage, typically with a HT modifier between 0 and -4. Large capacitors inflict stronger shocks, potentially causing heart failure (see p. 9).

Benjamin Franklin coined the name "battery" in 1749 for multiple interconnected capacitors, by analogy to artillery. This increases the shock! For two capacitors, apply an extra -2 to HT. For three or more, look up the number of capacitors in the "Linear Measurement" column of the *Size and Speed/Range Table* (p. B550), and apply the modifier in the "Speed/Range" column as a *further* penalty. Switching from a parallel to a series hookup trades off charge for voltage; such *voltage multiplier* circuits have been used in devices ranging from stun guns (p. 49) and defibrillators (p. 14) to particle accelerators. An improvised voltage multiplier can turn a battery's output into potent shocks; roll vs. Physics, Electrician, or Electronics Repair to create one. A "battery" of capacitors is a Simple invention (see p. B473) from TL5 on.

Supercapacitors (TL8; [1954] 1978) are intermediate between capacitors and rechargeable batteries. They can be rated for size like batteries (p. 16), but have the power output of batteries 10× larger (for example, an M supercapacitor substitutes for an L battery) for a duration of 1 minute. They cost 20× a comparably sized battery. The *power cells* in ***GURPS Ultra-Tech,*** pp. 18-20, might be advanced supercapacitors.

Leyden Jar (TL5). The original capacitor, a glass jar with both the interior and exterior covered with metal foil. A metal rod passes through an insulated stopper to connect with the interior. Size varies; the size defined here is based on a pint jar and delivers a nonlethal shock with -4 to HT when fully charged. Simple complexity. 0.75 lb. [1745].

Secondary Batteries

Advances in battery technology allowed reversing electrochemical reactions, using electrical energy to recharge batteries. *Secondary batteries* can catch fire or explode if recharged at excessive voltage – a plausible major bug for new inventions (see p. B474).

Rechargeable battery performance is adjusted from ratings for alkaline batteries (*Primary Batteries*, pp. 16-17). For many applications, one type can substitute for the other.

Lead-Acid Battery (TL6). The first rechargeable battery, used in early electric cars (p. 24). After World War I, electric starters powered by lead-acid batteries replaced hand cranks in gasoline-powered cars. Provides power one-third as long as alkaline batteries; reduce weight and cost by one-third. (Applying these modifiers to L and VL batteries matches the weights given in ***GURPS High-Tech.***) [1859] 1881.

Car-Battery Recharger (TL6). Supplies DC to recharge a lead-acid battery. A medium-amperage setting recharges a battery in 5 hours. A high-amperage setting can start a car, or can recharge a battery in 1 hour, but has to be monitored for safety; roll vs. Electrician or Mechanic (Gasoline Engine or vehicle type). On a critical failure, the battery explodes with REF 0.05 (see p. B415), causing explosive crushing damage – 6d for an L battery or 6d×3 for an XL battery. Anyone within 1 yard for an L battery or 3 yards for an XL battery is splashed with strong acid (p. B428). $55, 12 lbs. 1881.

Nickel-Cadmium (NiCad) Battery (TL7). A rechargeable battery designed to substitute for a dry cell. Provides power one-third as long as alkaline batteries. Same weight, but ×2 cost. [1899] 1946.

Nickel-Metal Hydride Battery (TL8). Replaces toxic cadmium with a hydrogen-absorbing alloy. Provides power as long as alkaline batteries. Same weight, but ×2 cost. [1987] 1989.

Lithium-Ion Battery (TL8). Provides power 10% longer than alkaline batteries; weight is unchanged, but cost is 20% higher. If short circuited, or if it is fails a HT roll after crushing injury or while being recharged with excessive voltage, it superheats, inflicting 3d burning damage *once* to a single hit location, and possibly starting a fire. Batteries of size M or larger produce large-area injury (p. B400) in the hex(es) where the batteries are located. A bomb could be improvised by confining an M or larger battery in an closed container; treat this as an explosive material with REF 0.25 (see p. B415). [1973] 1991.

Lithium-Ion Battery Recharger (TL8). A compact device that recharges a lithium-ion battery plugged into it. Household power. $55, 0.75 lb. 1991.

Flywheels

A flywheel stores energy in dense material spinning extremely fast. A set of coils acts as a motor when power is fed in, speeding it up, or as a generator when power is taken out, slowing it down. Peak output lasts up to 2 minutes. The power cells in ***GURPS Ultra-Tech*** might be advanced flywheels.

Flywheels come in weights comparable to larger batteries, though volume is greater.

Medium. Stores 2/3 the energy of an M battery, but peak output is 60× as high (equal to household power). $500, 1.5 lb.

Large. Stores as much energy as an L battery, but peak output is 100× as high (equal to industrial power). $7,500, 15 lbs.

Very Large. Stores as much energy as a VL battery, but peak output is 100× as high. $37,500, 75 lbs.

Steel (TL7). Only available in L and VL. ×4.5 weight; one-third cost.

Titanium (TL7). Only available in L and VL. One-third greater energy; ×3 weight; two-thirds cost.

Carbon Fiber Composite (TL8). Available in all sizes with statistics above.

Transmission

Electrical transmission systems get electrical energy from a power plant to places where it's used. During and after World War I, large-scale grids were created in cities, originally to support munitions factories. National governments later undertook rural electrification programs, from the Tennessee Valley Authority in 1933 in the United States to Chinese electrification programs starting in 2001.

Electric power lines, both in buildings and in power grids, are a source of lethal electrical damage (pp. B432-433). With shocks from power lines, current is roughly proportional to voltage, so damage can be based on voltage.

Voltage	*Current Source*	*Damage*	*Notes*
45-67V	Radio battery	1 point	[1, 2]
110-120V	Household (U.S. and Japan)	1d-3	
220-240V	Household (other countries); major appliance	1d+1	
480V	Industrial	3d	
1,000V	High-voltage power supply	5d	
1,500V	Third rail; overhead line	6d	
×10		+6d	[3]

Notes

[1] Supplies power to tube cathodes and plates in early radios.

[2] Can be treated as an M battery.

[3] Treat higher voltages as 6d×2, 6d×3, etc.

"Jutht put me near enough copper and thinc and athid, thur," he said, "and then we thall thee ***thparkth.****"*

– Terry Pratchett, ***Thief of Time***

Low-Voltage Systems

Early transmission systems used the voltage they provided to customers, limited to low voltages for safety. Edison's system, set up in 1882, provided 110 or 220 volts. Low voltage required high current to supply enough power, and power lost to resistance depends on the *square* of current. A power line a mile long might waste 5-10% of the power it carried! This limited power transmission to local networks, such as the square mile of Manhattan served by Edison's Pearl Street Station.

Cutting off power in a low-voltage system requires an Electrician roll. Failure by 5 or more, or critical failure, results in lethal shock based on the voltage. Roll at -1 if working with insulated tools but without safety equipment, and at -5 if working with improvised tools. The same rolls can be used to steal power; for continuing theft, roll vs. Camouflage to hide the added connections. Devices operated with stolen power require daily HT-2 rolls for reliability (p. B485), and a critical failure can start a fire (*Electrical Hazards,* p. 9).

The Battle of the Currents

When Edison's commercial rival, George Westinghouse, set up an alternating current (AC)-based system (*High-Voltage Systems,* below) using inventions of Tesla, Edison took up a propaganda campaign to show that AC was unsafe. In 1888, this became a public controversy after poorly maintained high-voltage lines caused several deaths.

During the same period, experimental investigation of electric shock led to proposals for its use as a humane alternative to hanging. Experimental tests had shown that AC killed animals at lower voltages than direct current (DC), so AC was adopted for the electric chair, at a typical voltage of 1,800 volts (6d×2 burning damage). Records of mishandled executions later raised doubts about its "humaneness."

Edison's opposition wasn't entirely emotional. Early AC generators couldn't operate reliably at the same frequency, so they couldn't be connected together to supply extra power; and they couldn't work with batteries, which used DC. Adjusting to heavy or light demand was difficult.

Despite these issues, the superior efficiency of AC won out, as its technical problems were solved. By 1890, Edison Electric was developing its own AC power systems.

Power Outlet (TL6). A socket that can be installed in a wall to provide household or major appliance power with an Electrician+4 roll. Grounded outlets become standard during the 20th century. A 10-pack is $5, 1 lb. [1885] 1915.

They finger death at their gloves' end where they piece and repiece the living wires.

– Rudyard Kipling, "The Sons of Martha"

High-Voltage Systems

High-voltage transmission avoids power loss, using *transformers*, which require alternating current (AC; see *The Battle of the Currents,* above). Transformers with iron cores (developed in 1885) convert low voltage and high current to high voltage and low current, and then lower voltages again for users. A power line with 10× the voltage supplies the same power with 1/10 the current and *1/100 of the power loss*.

The first high-voltage system was set up in London in 1889, at 10,000 volts. Main power lines operated at 10,000-110,000 volts before World War I (6d×2 to 6d×3) and at 220,000-765,000 volts later (6d×4). Local distribution typically uses 15,000 volts (6d×2).

Lines above 150,000 volts create intense electric fields that can induce current within the body without physical contact, at up to 1 yard. Treat this as a variation on nonlethal shock (p. 9); roll vs. HT, and use the margin of failure as a penalty to skill rolls from numbness or distracting sensations. A critically failed roll has stunning effects. Wearing a Faraday suit (p. 15) prevents these effects.

Wireless Power

Proposals to send power wirelessly began with Tesla's work in the 1890s, leading to the Tesla coil (p. 12). However, long-distance wireless power transmission proved unworkable. Recently developed technologies provide much lower power levels at shorter ranges.

Inductive charging, a near-field effect, uses oscillating magnetic fields to transmit power. Devices such as cordless phones and electric toothbrushes now have wireless chargers; free-standing chargers are becoming increasingly available for cell phones. [1978] 2010.

Other devices use radio waves to transmit power, going back to the resonant cavity microphone (p. 44). *Radio-frequency identification (RFID)* tags (p. 43) are a widespread application of this method, based on the *rectenna* ("rectifying antenna"). Large-scale rectennas have been used experimentally to transmit household or major appliance power via microwaves at a 1-mile range, with possible application to drone aircraft (p. 46). Average complexity. [1964].

Power Meters

The sale of electric power requires measuring customer power use. In an electromechanical power meter, a disc spinning at a rate proportional both to voltage and to amperage drives a register similar to an odometer. Between 2000 and 2010, these systems were largely replaced with solid-state systems based on analog-to-digital converters. Often these are read remotely by the power company, using digital signals (see *Transmission and Recording,* p. 19) – which an ingenious spy might gain access to!

Wattmeter (TL6). A portable device that measures current power consumption. Roll vs. Electrician or any Electronics Repair skill to use. It can identify which power lines in a building are in use, or locate equipment drawing large amounts of power. $15, 0.5 lb. 1889.

Electrical Equipment

Energy is the ability to do work. In high-tech societies, electrical energy may do many kinds of work, with the aid of suitable equipment.

Heat and Light

Some of the earliest practical applications of electricity involved heat and light. The goal of providing electric lighting was one of the major forces that created the electric power industry.

Lighting

The illuminating effect of a lamp is measured in *lux* (amount of light per area); see *Light Levels* (below). Light levels can be estimated in the following way:

(1) Choose a *wattage rating* for the lighting element the lamp is designed to use. This is based on wattages of *tungsten filament bulbs* (p. 21), the standard light source for most of the 20th century. Standard wattages are 40, 60, or 100 watts; flashlight bulbs are rated at 1 or 1.5 watts.
(2) In the *Light Sources Table* (p. 22), find the *relative efficiency* for the type of lighting element being used. For a *battery-powered* lamp, multiply the time its batteries last by the relative efficiency. For an *externally powered* lamp, divide the rated wattage by the relative efficiency to find the actual wattage; for example, an LED bulb rated at 100 watts has relative efficiency 6 and actually uses 17 watts. This rarely makes a difference in play, but it allows more lamps to be used on the same circuit.
(3) Each type of lamp has its own distinctive geometry (see *Lamp Types,* pp. 21-22). Multiply its rated wattage by the *effect multiplier* for its geometry (see the *Illuminating Effect Table,* p. 22) to find how many lux it provides. Use this to determine the illumination level in a 1-yard radius or in the area where a beam is focused (*Light Levels,* below). Adjust the illumination level for increased range as needed (*Light Levels,* below).

Arcs

The electric arc was the first practical application of electric power, using current flow between two electrodes to create light and heat. Invented in 1810 by Humphrey Davy, it came into widespread use only after the invention of effective generators (p. 17).

Yablochkov Candle (TL6). Two parallel carbon rods 12" long separated by insulation, joined at the top by a fuse. When power is supplied, an arc forms at the top, and progressively erodes the rods, taking 2 hours. If extinguished, it cannot be restarted. Used mainly in spotlights, but also in streetlights (360° field). Major appliance power. $2, 0.25 lb. 1878.

Light Levels

The effects of electric light are defined in terms of light levels; see the *Illumination Levels* table. Below 100 lux, human vision is subject to darkness penalties (p. B358). Brighter light doesn't give bonuses, but is needed for some tasks: from 500 lux for reading or sewing up to 50,000 lux in a surgical theater. Without this, the relevant attribute or skill roll is at -2.

A light level of 200,000 lux, or any light five steps above what the eyes have adapted to, requires a HT roll to avoid being dazzled, at -1 per step past five. Success by 3+ avoids problems. Success by 0-2 requires re-adapting to the lower light. Failure dazzles (extra -4 to Vision) for minutes equal to the margin of failure, after which adapting to the lower light is necessary. Critical failure blinds for seconds equal to margin of failure and then works like normal failure.

A single lighting element provides its full illumination out to a 1-yard radius in a 360° or 180° field. Reduce this by one level at 2 yards, by two levels at 3-5 yards, and by three levels at 6-10 yards; each further ×10 radius gives -3 levels. Once this is equal to the area's overall light level, no further penalties apply; a lamp won't make a room darker! Devices that send out focused beams, such as flashlights or spotlights, can be treated as illuminating *only* the targeted area (but if one is being used, darkness penalties never exceed -9 in the larger area).

Any beam has to be targeted on an area, with Aim and Attack maneuvers, using DX as the base skill. Apply any penalties for partial darkness. On a successful Hearing roll on Quick Contest of Hearing vs. Stealth, apply -6, if this is better (but adjusted skill cannot exceed 9). On a failed roll, the light shines on an area left or right of the desired location by yards equal to the margin of failure; roll one die, with odd indicating left displacement and even for right displacement.

Illumination Levels

Penalty	Minimum Lux	Illumination Examples
-5	0.05	Half moon (clear sky), indicator LED
-4	0.2	Full moon (clear sky)
-3	1	Night light
-2	5	Twilight, flashlight beam, cell-phone screen
-1	20	Sunrise, sunset
0	100	Very overcast day, interior light
0	500	Reading light
0	2,000	TV studio
0	10,000	Daylight
0	50,000	Direct sunlight, surgical theater

Arc Welder (TL6). Uses the heat from a carbon arc to weld or cut metal. Inflicts 3d(2) burning damage per second. Industrial power. $70, 2.25 lbs. Replacement electrodes $1, neg. 1881.

Resistive Elements

In 1840, the heating effects of electric current were discovered. This effect was applied in the incandescent light and in resistance wire heating. See also *Medical and Surgical Tools* (pp. 13-14).

Carbon Filament Bulb (TL6). The first incandescent light. The filament is fragile, giving the bulb HT 8. Cooler and dimmer than modern bulbs. $2, neg. 1880.

Incandescent Bulb Heater (TL6). Four incandescent bulbs with a copper reflector that directs their heat outward. Gives too little heat to warm a room, but can lessen the chill for one person or warm the hands; +1 to HT to resist cold. Household power. $50, 2.4 lbs. 1891.

Hot Plate (TL6). A device using chromel inside a hollow steel tube as a cooking surface. Improvised equipment for Cooking or Housekeeping. Inflicts 1d-3 burn per second. Household power. $25, 6 lbs. 1906.

Resistance Wire Heater (TL6). A heater that can warm a moderate-sized room; +2 to HT to resist cold. Early models often had inadequate screening and could inflict 1d-3 burn per second. $25, 7 lbs. 1906.

Tungsten Filament Bulb (TL6). Tungsten bulbs had longer lives and better durability. $1.50, neg. Miniature bulbs are used in flashlights (p. 22) and as indicators. $5/dozen, neg. [1906] 1911.

Heating Pad (TL6). Provides moderate heat controlled by a thermostat. After 30 minutes, roll vs. HT to reduce the intensity of persistent pain one step (see p. B428 for definitions of steps). Household power. $15, 1 lb. 1912.

Cigarette Lighter (TL6). A small chromel coil on a plug handle is pushed into an automotive power outlet. After 1 minute, it can inflict 1 point burn damage, enough to light a cigarette (p. B433). [1921] 1925.

Flashbulb (TL6). An electric current from a camera heats and ignites a magnesium wire, illuminating a 180° hemisphere with 900,000 lux at 1 yard. Roll vs. HT to avoid being dazzled, at -5 if looking directly at the bulb. $1, neg. 1929.

Luminous Gases

Some forms of lighting involve the flow of electric current through ionized gases.

Neon Light (TL6). Brightly colored neon signs appeared in Paris before World War I. Designing a sign calls for a roll vs. Artist (Neon). Major appliance power. Cost and size are not standardized. [1898] 1910.

Fluorescent Light (TL7). Experiments with fluorescent lighting go back to 1859. The modern form, in which ultraviolet light emitted by mercury vapor activates a fluorescent coating, came into use in 1939. Compact fluorescent lights can replace incandescent bulbs. Household power. $3, neg. [1976] 1985.

Electromagnetic Heating

It's possible to heat objects using either near-field or far-field effects. See also *Medical and Surgical Tools* (pp. 13-14).

Handheld Induction Furnace (TL6). Uses magnetic induction to heat metals. This is a small model, with a crucible holding up to 4.5 lbs. of metal at the end of a long handle that can lift and tip it. Molten metal inflicts 3d burning damage at first contact! Major appliance power. $900, 45 lbs. [1870] 1900.

Microwave Oven (TL7). Uses microwaves to heat water and organic molecules in food inside a shielded enclosure, allowing rapid cooking, defrosting, and reheating. Control of heating is less precise: -1 to Housekeeping, -2 to Cooking. Household power. $100, 25 lbs. [1945] 1967.

Induction Cooker (TL8). Originally patented in 1909; early commercial models appeared in 1972. A high-frequency magnetic field produces current flow in a ferrous metal pan. The surface the pan rests on is not heated, nor is spilled food. Heating is almost instantaneous, providing precise control: +1 to Cooking and Housekeeping, but with initial unfamiliarity penalties. This countertop model uses household power. $50, 7 lbs. 2000.

Solid-State Devices

Semiconductor transducers (see p. 12) can operate in reverse, turning electrical energy into heat flow or light emission.

Laser Pointer (TL8). A small (often pocket-sized) device containing a diode laser whose beam shows up on a distant surface as a point of light. Used as a pointer or a cat toy – or an improvised weapon to dazzle a foe by targeting the face (*Ranged Weapons Table,* p. 51). T/1 year. $7, neg. 1981. After 2000, green laser pointers are available that have greater effective range.

Solid-State Heat Pump (TL7). In the Peltier effect, electric current flowing through a junction of two different metals results in heat flow across the junction. Heat pumps are less efficient than refrigerators, but have neither moving parts nor fluids, make no noise, and almost never need repair. An insulated chest 18" on a side holds 2.5 cubic feet of food or canned drinks and cools to 20°F below the surrounding temperature. Reversing the current with a built-in switch makes it a warmer. Automotive power. $110, 15 lbs. [1970] 1985.

Light-Emitting Diode Bulb (TL8). A semiconductor device that emits light when current passes through it. LEDs for display became commercially available in 1968 (TL7). Bulbs using multiple LEDs appeared at TL8. $5, neg. [1907] 2010.

Lamp Types

Each type of lamp is designed to illuminate an area with a specified geometry; see the *Illuminating Effect Table* (p. 22) for options.

For lamps that emit conical beams, instead of keeping the rated wattage the same, and using less actual power (multiplying the battery life by the relative efficiency), it's often useful to substitute a brighter lighting element. For example, an LED flashlight can be much brighter than a flashlight with an incandescent bulb. Keep the battery life or actual wattage unchanged, and multiply the rated wattage (and thus the lux obtained) by the relative efficiency (see *Light Sources Table,* p. 22).

Spotlight (TL6). Designed for use in theaters or other public venues or on movie sets to light performers or speakers (rugged models have other applications).

Can be clamped to a rail or bracket. Conical beam range 100 yards. $30, 3 lbs. 1878 for arc lights (p. 20); 1904 for incandescent lights (see *Resistive Elements,* p. 21).

Floor Lamp (TL6). A freestanding upright lamp between 5' and 6' tall, with a weighted base and usually a shade to diffuse the light. Often decoratively styled. Exposed lamp. $30, 10 lbs. 1881.

Table Lamp (TL6). A lamp that stands on a table, usually with a shade to diffuse the light. Often decoratively styled. Exposed lamp. $15, 4 lbs. 1881.

Desk Lamp (TL6). A small fixture with a heavy base that sits on a desktop or a clamp that attaches to its side. A flexible neck or a floating arm lets the user aim the light. Close-range beam. $20, 4.5 lbs. 1911.

Flashlight (TL6). Uses dry cells and a miniature bulb as a portable light source. It didn't take off commercially until the development of the tungsten filament bulb (p. 21). Typically uses a 1.5-watt bulb. Conical beam range 10 yards. 3×S/30 hours. $20, 1.25 lb. A *rugged* model is $40, 1.5 lb., with HT 12 and DR 4. [1899] 1911.

Penlight (TL6). A smaller flashlight; users include theater ushers and doctors checking pupil reflexes. Typically uses a 1-watt bulb. Conical beam range 1 yard *or* close-range beam. XS/5 hours. $10, 0.25 lb. 1930.

Ceiling Lamp (TL7). A fixture mounted on, or recessed into, a ceiling. Recessed lamp. $25; 2.5 lbs. 1945.

Light Sources Table

TL	*Light Source*	*Relative Efficiency*	*Notes*
6	Arc light	0.5	[1]
6	Carbon filament bulb	0.25	[2]
6	Neon light	3	[3]
6	Tungsten filament bulb	1	
8	Compact fluorescent light	5	
8	LED bulb	6	
8	Prototype advanced LED bulb	20	[4]

Notes

[1] Only available with rated wattage of 100 watts (actual wattage of 200 watts).

[2] *Actual* wattages of 40, 60, and 100 watts give *rated* wattages of 10, 15, and 25 watts.

[3] Rated wattage variable; used for display rather than illumination. Treat any neon sign as *in plain sight* (+10 to Vision rolls) at illumination levels -2 or lower.

[4] Treat as an invention of Simple complexity.

Electrochemical Processes

Batteries turn chemical energy into electrical energy, and rechargeable batteries turn electrical energy back into chemical energy, but other processes use electrical energy to do chemical work. Typically these use a high-voltage battery, or a generator, to make a cell work backward, forcing electrons in at the anode and removing them from the cathode.

Electrodeposition

Shortly after 1800, European experimenters discovered *electroplating:* coating the metal cathode of a cell with a different metal, either from the anode or from the electrolytic solution. The process came into industrial use in 1840, originally mainly for gold and silver plating. At TL6, increased availability of electrical power allowed larger-scale use, producing metal parts with enhanced resistance to wear or corrosion or attractive surfaces.

Brush Electroplating System (TL6). A relatively small system, suited for a home workshop or small business. Uses an electrified brush to apply a metal solution at a precise thickness. Roll vs. Artist (Sculpting), Jeweler, or Machinist. On a failure, the coating is uneven; on a failure by 5 or more, the surface wasn't properly cleaned and parts remain uncoated. Can be used with gold, silver, copper, zinc, tin, or nickel – or with brass or bronze at -2 to skill. Major appliance power. $600, 10 lbs. [1938] 1948.

Electrolysis

Direct current was used to break down ionic compounds just after the voltaic pile (p. 16) was invented. This led to the discovery of eight new elements, and later became industrially important in large-scale production of aluminum, changing it from a rare precious metal (worth more than $1,100 per pound in 1859) to an inexpensive raw material.

In an emergency, electrolysis of water can provide oxygen. Producing 0.75 cubic feet per hour (sufficient for survival with no exertion; see p. B351) requires household power or L/12 hours. The apparatus is stationary and requires a roll vs. Chemistry to set up, using a field lab (***High-Tech,*** p. 50).

Magnets

Generation of magnetic fields by electric currents (*Electromagnetism,* p. 4) made controllable magnetism possible. This quickly became the basis for useful devices. See also *motors* (pp. 23-24) and *relays* (see p. 24).

Electromagnets (TL5)

A typical electromagnet is a cylindrical coil of wire. A current flow generates a magnetic field running down its interior. Magnets can either hold onto ferrous metal or pull it toward themselves across a short distance.

A magnet's *effective ST* is based on the intensity of its field. Its maximum portative load is 10× the corresponding Basic Lift.

Illuminating Effect Table

Type	*Geometry of Illuminated Area*	*Effect Multiplier*	*Notes*
Exposed lamp	360° sphere	×1.5	Out to 1-yard radius
Recessed lamp	180° hemisphere	×3	Out to 1-yard radius
Conical beam	Aimed at large area	×6	Cone width 2 yards
Close-range beam	Aimed at small area	×30	Cone width 32"

Practical magnets have iron cores that concentrate the magnetic field, quickly building up a strong field (about 1.6 tesla). Treat them as having ST equal to 8× their interior diameter in inches. (See also *Magnetic Lock,* p. 42.) For example, an iron-core magnet with interior diameter 5" has ST 40 and BL 320 lbs.; it can support 3,200 lbs.

More intense fields can be obtained from air-core *superconducting magnets*; typical ST is 100× interior diameter (for a field of 20 tesla). Superconducting magnets are refrigerated in liquid nitrogen. Suitable high-temperature superconductors were discovered in 1986.

Magnetic fields fall off quickly with distance, limiting the range at which they can attract ferrous metal. For gaming purposes, assume that this is equal to the *length* of the magnetic coil.

Portable Electromagnet (TL5). A small but powerful electromagnet, 2" in diameter (1" interior diameter) and 1" thick (SM -7), able to lift 130 lbs. (effective ST 8). M/16 hours or automotive power. $15, 0.65 lb. [1824] 1830.

Bells and Buzzers (TL5)

The force of a small electromagnet can be used in a telegraph sounder (p. 26) or a bell or buzzer. When current flows, a hammer strikes a metal bell, once or repeatedly, or a piece of metal moves back and forth, making a buzz (Hearing distance is 4 yards). A buzzer can be improvised from a relay (see p. 24) with an Electrician roll. S/12 hours or household power. $15, 1 lb. [1839] 1847.

Motors

Motors are another type of electromagnetic device, more widely used than all the others together.

Household Devices

Motors began to be relied on for household appliances almost as soon as electric power lines were available.

Large Fan (TL6). A device for moving air, often used for cooling; +2 to the user's HT to withstand ordinary heat. Household power. $20, 6 lbs. 1882.

Small Fan (TL6). Stands on a desk, table, or other surface, or is clamped in place; the bonus to the user's HT is only +1. Household power. $30, 3 lbs. 1882.

Vacuum Cleaner (TL6). Uses a motor-driven fan to suck air, dirt, and tiny things into a bag. Can be run over the floor or used with nozzle attachments that reach into tight spaces. Household power. $90, 15 lbs. [1901] 1905.

Sewing Machine (TL6). Sewing machines, invented at TL5, were quickly adapted to use electric motors. Machine sewing is 5× as fast as hand sewing. Household power. $55, 15 lbs. [1889] 1910.

Cyclonic Vacuum Cleaner (TL8). A vacuum cleaner with a detachable filtered collection vessel in place of a bag; filters must be cleaned after use. Household power. $200, 16 lbs. 1979.

Handheld Vacuum Cleaner (TL8). A small vacuum cleaner, sometimes powered by batteries. Household power or 2×XS/13.5 hours. $35, 2.5 lbs. 1979.

Sewing Machine (TL8). A programmable machine that carries out complex decorative stitches automatically without a skill roll. Household power. $150, 15 lbs. 1990.

Small Fan (TL8). A small fan powered by rechargeable batteries. XS/8 hours. $15, 1.75 lb. 1991.

Office Devices

Motorized equipment allowed a variety of office jobs to be done faster or with less human labor.

Electric Typewriter (TL6). Pressing the keys directs mechanical energy from a motor to a typebar, producing more even impressions on the page and increasing typing speed (*Typing,* p. B228). Household power. $75, 20 lbs. 1900.

Mimeograph (TL6). Presses a stencil cut by hand or by a typewriter (without a ribbon) onto sheets of paper, letting ink through to make impressions. The standard model places the paper on a revolving drum, allowing up to 45 copies per minute. Household power. $190, 15 lbs. [1887] 1914.

Shredder (TL7). First used in Germany during World War II; the now standard crosscut shredder (which cuts paper into small pieces rather than long strips) was invented later. Came into widespread use in the late 1980s. Roll vs. Forensics to reconstruct shredded documents, at -5 if they have been through a crosscut shredder. Household power. $25, 8 lbs. [1935] 1959.

Electric Typewriter (TL7). A design introduced at TL7 with letters mounted on the surface of a metal ball about the size of a golf ball; allows changing typefaces. This device is priced as cutting-edge: $375, 37 lbs. 1961.

Photocopier (TL7). Early photocopiers were stationary devices using chemically based photography, taking 5 minutes per copy (starting 1907), or electrostatically based xerography, capable of seven copies per minute (invented in 1937; commercially available 1960). Desktop models are suitable for smaller offices. At TL8, similar functions are incorporated into *multifunction printers* (below). Household power. $30,000; 65 lbs. 1963.

Daisy Wheel Printer (TL7). A computer-controlled text output device in which a disk rotates to impress a selected character on a sheet of paper (similarly to the metal ball in a TL7 electric typewriter). Capable of five words per *second.* Household power. $100, 20 lbs. (1939) 1970.

Dot Matrix Printer (TL7). The first pixel-based printer, capable of outputting images as well as text. Poor resolution gives -5 to Artist rolls. Household power. $110, 20 lbs. [1944] 1970.

Multifunction Printer (TL8). Combines the functions of an inkjet (p. 24) or laser (p. 33) printer, a scanner (p. 33), a photocopier (above), and a fax machine (p. 27). Household power. $100, 12 lbs. 1998.

Workshop Devices

A well-equipped home or professional workshop has a variety of electrically powered devices. The smaller ones are portable.

Shopvac (TL6). A larger vacuum cleaner able to clean up wet areas (including crime scenes, if it's carried away after use; -2 to subsequent Forensics rolls). Household power. $130, 30 lbs. 1905.

Power Drill (TL6). A handheld tool in which a small electric motor turns a drill tip. A typical model inflicts 1d+2(2) pi++ damage on materials such as wood and plaster. The standard design has a trigger switch and pistol grip; early models have clumsier arrangements (-2 to skill). Household power. $20, 4.5 lbs. [1895] 1917.

Circular Saw (TL6). A handheld saw with a rotating blade; also called a "buzzsaw." A typical model inflicts sw+3(2) cut damage on wood or other materials; for hard materials such as concrete or brick, an abrasive diamond blade inflicts sw+3(5) cut damage. Major appliance power. $125, 20 lbs. 1924.

Compact Circular Saw (TL7). Powered by internal batteries; inflicts sw+1(2) cut damage per second, or sw+1(5) cut damage with an abrasive diamond blade. S/30 minutes. $60, 6.5 lbs. 1980.

Compact Power Drill (TL7). Powered by internal batteries. 3S/1 hour. $35, 5.5 lbs. 1961.

Vehicles

Experiments with electrically powered vehicles began in the early 19th century, using lead-acid batteries (p. 18). Commercial models appeared in the 1890s, and by 1900, a third of automobiles were electric. However, they were expensive; the gasoline-powered Model T Ford, introduced in 1908, sold for less than half the price. Electric vehicles began to return to the market in the 1990s, partly as a result of environmental legislation, and gained popularity with the release of the Tesla Roadster in 2008 – though they were still expensive! Operating them requires Driving (Automobile).

Electrobat (TL6). A line of automobiles powered by lead-acid batteries. The first model was impractically heavy (4,250 lbs.); statistics are given here for the second model, used for cab service in several eastern U.S. cities. It had two seats in front and a raised platform at the rear for the driver. Recharged by driving into a charging station and swapping the batteries for a new set. 75 minutes/64L. $30,000, 1,650 lbs. 1895.

Tesla Model S (TL8). A five-door liftback automobile; the statistics given here are for the 75-kWh model with all-wheel drive. A full recharge with major appliance power takes 8 hours; an optional second charger reduces this to 4 hours, if power is available. $74,500, 4,608 lbs. 2012.

MEMS

Microelectromechanical systems (MEMS) are an outgrowth of integrated circuits (*Miniaturization,* p. 6) that perform mechanical functions on a microscopic scale. They are standard components for Engineer (Microtechnology) and Mechanic (Micromachines). They are used as sensors, as in accelerometers (p. 13) and small microphones; in digital micromirror devices (p. 34); and in lab-on-a-chip systems (p. 13).

Inkjet Printer (TL8). A MEMS-based device that deposits pigment directly onto paper. Allows Artist rolls at no penalty. May be incorporated into a multifunction printer (p. 23). Household power. $110, 12 lbs. [1977] 1984.

3D Printer (TL8). A device for fabricating models or small parts by laying down successive layers of polymers according to a design stored in a computer (pp. 36-38); often used for making prototypes. To use, roll vs. Machinist or vs. Artist (Sculpting), at -2 until familiar with this design method. Larger industrial-scale versions used for *additive manufacture* of small parts may work with metals rather than polymers. Household power. $300, 25 lbs. [1981] 1992.

Electrically Powered Vehicles Table

Terms and notation are as defined in *Vehicle Statistics* (pp. B462-463).

TL	Vehicle	ST/HP	Hnd/SR	HT	Move	LWt.	Load	SM	Occ.	DR	Range	Cost	Loc.
6	Electrobat II	47	0/4	10	2/10	1.15	0.325	+2	1+2	7	25	$30,000	O4W
8	Tesla Model S	67	+1/4	12	7/70	3.1	0.8	+4	1+4	5	260	$74,500	G4W

ELECTRICAL CONTROL

Electrical devices need controls to direct their internal flow of electricity. At TL5-7, controls affect a device's operation directly. TL8 sees computerized systems, where the user interacts with a dedicated computer and the computer operates the device. (See *Physical Controls,* pp. 39-40, for common interaction options.)

SWITCHING

The simplest controls turn devices on or off. The oldest device for doing this is the manual switch. The first form, the *knife switch,* has a metal lever with an insulated handle, which can be pushed into a slot. Critical failure in operating the device can result in shock from exposed conductors. At industrial or higher voltages, *arc flash* can occur on critical failure when the switch is opened (*Electrical Hazards,* p. 9).

The higher voltages of power lines (p. 18) led to the development of *safety switches* with protective covers, worked by toggles, pushbuttons, or pull chains. *Rotary switches,* operated by turning a knob, can have three or more positions, which can be used to select different settings.

Some manual switches conduct current only while pressure is applied, springing open when released. The *telegraph key* (p. 26) is such a device. A *dead man's switch* has a button that is held down continuously by the operator; if it's released, the device stops working – or an alarm or a bomb goes off!

Early telegraphs used *relays,* in which a magnet powered by incoming current controls a switching mechanism, turning on a stronger current that can carry the signal further (hence the name). At TL6, relays were used to control high-voltage circuits, as well as in automatic telephone exchanges (see p. 26) in the early 20th century.

The 20th century saw the invention of *electronic switches*. The *thyratron,* a gas-filled vacuum tube that could be switched into a conductive state by a low voltage, came on the market in 1928 (TL6), and is still used in high-powered applications such as particle accelerators and large radar systems. The *silicon-controlled rectifier* or *thyristor,* a solid-state equivalent, came on the market in 1957 (TL7).

Variable Power

It's often useful to run devices at settings using different amounts of power. This can be achieved by adding a variable resistance to the circuit, or, for AC power, a *variable autotransformer,* in which the power supply is connected to a coil and the device to a tap in the middle of the coil. Such controls may use pushbuttons (as on a blender) or switches with multiple settings (as in a three-way lamp), or allow continuous variation of power (as with a dimmer). Advanced versions use computer controls at TL8.

Remote Control

An electrical device at the end of a wire could be turned on or off, or sped up or slowed down, from a distance. This was the start of *remote control.* Experiments with remote control by wire began early in TL6; early experiments with radio included Tesla's radio-controlled boat in 1898. Radio-controlled models became a hobby in the late 1940s.

Most early devices had to be in the operator's field of view. During World War II (TL7), television cameras were installed in missiles as targeting systems (*Fuzes and Guidance,* pp. 48-49); this led to the emergence of *teleoperation*. See also *Reconnaissance UAVs* (p. 46).

Remote control of consumer devices by wired connections was introduced for television sets in 1950 (TL7). In 1955, wireless remotes appeared, using light, ultrasound, or infrared. At TL8, a wide range of devices can be controlled in this way, and Wi-Fi (*Local Networks,* p. 41) has been used for remote control. Remote-controllable equipment sells for 10% above standard equipment. The proposed "Internet of things" would make such capabilities universal.

Telautograph (TL6). A device for sending messages to a remote location as they are written. The sender moves a stylus over a sheet of paper; vertical and horizontal position sensors control the motion of another pen at a receiving station. This allows legally valid signatures to be made at a distance. Household power. $750, 15 lbs.; $375, 10 lbs. for each additional receiver. [1888] 1900.

Telepresence Robot (TL8). A wheeled platform that supports a teleconferencing unit at a height of 4'6", allowing a remote operator to view and navigate an indoor environment at Move 2 and interact with people there. L/2 hours. $1,600, 70 lbs. [1990] 1993.

Smart Plug (TL8). A remote-controllable switch inserted between a three-pronged plug and a grounded household outlet, letting a device be turned on and off at up to 30 yards or via a network (p. 41). $10, neg. 2015.

Safety Devices

As the dangers of electricity were realized, inventors came up with devices to protect against them. These devices turn critical failures (which can cause electric shock or property damage) into ordinary failures involving only power loss.

Fuse (TL6). A piece of conductive material with a narrow cross-section, which melts when high current flows through it. Improvised fuses protected telegraph stations against lightning strikes. Edison developed a commercial version for his power-distribution system; if too much power was drawn (perhaps by a short circuit), creating a fire hazard, the fuse burned out and shut it off. Replacing a fuse with a penny restores power, but any further failure is critical! [1864] 1890.

Circuit Breaker (TL6). A device similar to a relay (see p. 24), in which excess current opens an internal switch and locks it open, shutting off power. Unlike a fuse, it can be reset. [1879] 1924.

Emergency Stop (TL6). A special control, also known as a *kill switch,* that can shut a device down immediately in an emergency (for example, to prevent injury). A machine shut down in this way must roll vs. HT to avoid equipment failure (p. B485). Emergency-stop controls are normally highly visible (+10 to Per).

Ground Fault Interrupter (TL7). Another form of circuit breaker, built into an electric outlet or a power plug; also called a *residual-current device*. Shuts off power when the current going out one wire doesn't equal the current coming back the other – meaning that some of it is taking a different path, such as through a shock victim. Acts faster than a shock can affect the human heart. Can be designed to protect against lethal electric shock, fire hazards, or damage to equipment. 1956.

Automatic Control and Robotics

The first electrical automatic control device, the *thermostat* (invented in 1889 by Albert Butz) turned a heater on or off to maintain a steady temperature; its applications range from room heating and cooling to sophisticated chemical apparatus. This was an example of *feedback control,* in which a device's operation is modified in response to changes in something that it affects.

Robotics goes beyond basic automatic control, using computer programs (p. 38) to decide whether and how to perform a task – typically one that's repetitive or dangerous, or takes place in a hostile environment. Some robots are humanoid and imitate human activities; however, many such activities are surprisingly difficult to program – for example, walking on two legs. Most robots are designed to perform limited, specialized tasks. For a look at advanced robots, see ***GURPS Ultra-Tech.***

Robovac (TL8). The *autonomous robotic vacuum cleaner* travels about a floor, using built-in sensors to navigate and select suitable cleaning modes without human control. It takes longer than a human being would, but works all day unsupervised. Later models (since 2007) can find their way to charging stations when their batteries are running down. M/1 hour. $280, 8 lbs. [1996] 2002.

Chapter Four
Signals and Waves

Early electronics grew out of communications technology. Hertz's experimental demonstration of radio waves made wireless messages possible. Vacuum tubes brought radio to maturity, and they could also handle audio and video signals.

For details about terms used in equipment descriptions, see *Understanding the Devices,* pp. 8-9.

Modes of Transmission

Signals need a physical carrier. The development of electronic communication has seen several different carriers in use, from early experiments with telegraphy to present-day broadband.

Wired

The earliest electrical signals were sent over wires and could only go where the wires went. Wires carried coded text, voices, still pictures, and instrument readings, or *telemetry* (see *Transmission and Recording,* p. 12). For typical prices for telegrams and telephone service, see ***GURPS High-Tech,*** pp. 36, 37.

Telegraphy

Telegraphic experiments began in 1774, using static electricity, and increased after the invention of the *voltaic pile* (p. 16). Early designs used multiple wires, often one for each letter of the alphabet. Samuel Morse's telegraph, combining battery power, electromagnetism, and a code in which all the letters could be sent over a single wire, won out internationally by 1851 and was used in the transatlantic telegraph system completed in 1866. Using it requires Electronics Operation (Comm).

Early telegraphs recorded incoming signals on paper tape (*Register Telegraph,* ***High-Tech,*** p. 36). This apparatus was often controlled by *relays* (see p. 24), which responded to weak signals from distant stations. Skilled operators could interpret a message from the clicking of a relay, without waiting for the paper tape. This led to the invention of the *sounder,* designed to make more easily heard clicks. Transcribing a message in this way requires a *Per*-based roll against Electronics Operation (Comm) with Hearing modifiers; the roll is unmodified at 9" for a relay or at 2 yards for a sounder (*Hearing Distance Table,* p. B358).

A mile of wire costs $1,500 and weighs 350 lbs.

Telegraph Key (TL5). A specialized electric switch that sends a telegraphic signal by turning on a current when pressed down. L/8 weeks for 20 miles; each added battery adds 10 miles. $25, neg. [1837] 1844.

Telegraph Sounder (TL5). Similar to an electric bell (p. 23), producing clicking sounds when current flow starts and stops. $125, 3 lbs. 1850.

Teletype (TL6). A device that uses telegraph lines to transmit signals from a typewriter keyboard to a teleprinter – or, after 1924, sends such signals via radio. It doesn't require skill in Morse code, but only in typing, for which it counts as a familiarity; typing speeds are as for electric typewriters (p. B228). Nearly all commercial models use *Baudot code* (the basis for *baud* as a unit of data transmission), automatically generated within the keyboard. A network of teletype exchanges (*telex*) emerged in 1931; operators developed shorthand expressions such as "CU L8R" long before texting. Household power. $5,000, stationary. [1908] 1922.

Telephony

Experiments with *acoustic telegraphy,* in which a single wire carried multiple signals at different sound frequencies, led to the telephone, which carries the varying frequencies of a human voice. The first commercial telephone exchange opened in 1878 in New Haven, Connecticut.

The first transcontinental call was made in 1915, between New York and San Francisco, using a vacuum-tube amplifier (see *Audio Amplification,* p. 32).

The Strowger switch, invented in 1891, made automatic telephone exchanges possible and gradually replaced human-operated switchboards. Dial telephones became a mass-market product in 1919. Telephone operators use Electronics Operation (Comm); no skill roll is needed for subscribers.

Voice-Powered Telephone (TL6). The first telephones used microphones that generated their own current from the power of the speaker's voice. A hand-cranked magneto created power to ring a bell at the other end. This technology remained in use through TL7 in military telephones in the field and is still used on naval ships. $50, 5 lbs. 1876.

Telephone (TL6). Early telephones were powered by carbon-zinc batteries. 3×S/1 month. $30, 5 lbs. 1877. After 1900, telephone exchanges provided power, and telephones *became smaller:* $25, 3 lbs.

Intercom (TL7). A short-range system for wired voice transmission, with a microphone and a loudspeaker at each end. This basic version has two stations that can be up to 60' apart. 2×XS/1 month or household power. $35, 1.5 lb. 1940.

Fax

A fax machine uses a photoelectric sensor to scan a flat image, pixel by pixel. Experimental systems date to 1911; "wirephoto" became commercially available in 1921, and "radiophoto" in 1926. By 1929, a full page could be sent in a minute over a dedicated phone line. Digital fax appeared in 1960, and analog fax was discontinued in 1996. Digital machines can send three pages per minute. No skill roll is required. Household power. $30, 0.75 lb.

Wireless

The telegraph and telephone depended on wires, which were costly to set up and needed to be maintained – and could be cut by an enemy. The success of telegraphy led to speculations that it might be possible to send electrical signals without wires. Early experimental devices depended on near-field effects with limited range. Long-distance wireless messages became possible with the invention of radio.

Radios

Each radio has a defined *range,* used when two systems of the same type are in communication. See *Mix and Match* (p. 28) for rules on combining different systems. A skilled operator can receive signals at greater distances with a roll vs. Electronics Operation (Comm) at -1 per added 10% range, with a maximum increase of 100%. Broadcast signals that are *intended* to be received easily require no skill roll to be picked up at normal range and without interference. In code or data transmission, the range can be increased by repetition; the number of repetitions required is the square of the factor of range increase. For example, doubling the standard range requires four repetitions, which take 4× as long.

Radio was subject to interference from lightning, electrical machinery, or other signals (including intentional jamming; see pp. 49-50). This can be represented as a penalty to rolls to detect a signal, from -1 to -10, similar to those for Obscure; -10 represents a completely blocked the signal. Under favorable conditions, a *bonus* may apply; +4 could represent a strong signal or an exceptionally clear channel.

Radio size categories are as defined in ***High-Tech,*** pp. 37-38. Specifications given here are for code transmission (*radiotelegraphy*), which is available at all stages in the development of radio, and costs have been reduced 50% to reflect this. Audio and video transmission are discussed later (audio on pp. 30-33; video on p. 33-34).

Large Radio (TL6). 50-mile range. 3×M/3 hours. $1,750, 100 lbs.

Large Radio (TL7). 100-mile range. VL/10 hours. $2,500, 100 lbs.

Large Radio (TL8). 200-mile range. External power. $7,500, 100 lbs.

Medium Radio (TL6). 5-mile range. 4×M/14 hours. $1,250, 30 lbs.

Medium Radio (TL7). 10-mile range. 10×S/30 hours. $1,750, 25 lbs.

Medium Radio (TL8). 35-mile range. 2×M/30 hours. $1,000, 8 lbs.

Small Radio (TL6). 1-mile range. 3×S/10 hours. $125, 5 lbs.

Small Radio (TL7). 2-mile range. 3×S/8 hours. $250, 2 lbs.

Small Radio (TL8). 5-mile range. 3×XS/10 hours. $125, 0.5 lb.

Tiny Radio (TL7). 0.5-mile range. XS/5 hours. $50, 1 lb.

Tiny Radio (TL8). 2-mile range. XS/10 hours. $25, 0.25 lb.

Who Invented Radio?

After Heinrich Hertz's experiments (see p. 4), several different scientists and inventors explored practical applications of "Hertzian waves." In 1891, Nikola Tesla's work on wireless power led to the Tesla coil (p. 12), which generated radio waves at 15,000 hertz. Tesla speculated about wireless telegraphy, but he envisioned it as based on near-field effects. Oliver Lodge's research on lightning protection (*Lightning Rod,* p. 15) led to his independent discovery of spark-gap transmission. He demonstrated this in 1894, inventing the *coherer* (see p. 28) to detect the signal. Also in 1894, inspired by Lodge's work, Jagadish Chandra Bose created a transmitter for millimeter waves and a crystal detector, work that wasn't followed up on until after World War II. Guglielmo Marconi, also in 1894, adapted the coherer to pick up radio waves created by lightning. Later that year, he developed a transmitter and antenna that achieved a 2-mile range.

Tesla patented his system in the United States in 1897; Marconi patented his in the United Kingdom in 1896, but didn't file in the United States until 1900. The resulting legal disputes went on until 1943. Marconi was far more successful in developing the technological and commercial applications of radio, and benefited from an alliance with Tesla's American rival Edison. However, Tesla's claims to priority still have supporters!

Mix and Match

High-Tech, p. 38, provides a simple rule for determining range when two different radios communicate with each other. But its results can be implausible with radios at different TLs. Here is a different rule that produces more general results: Find the product of the ranges of the two radios, and take its square root to obtain the range when they're used together.

Example: A trench radio is used with a crystal receiver (see *Crystal-Based,* below). The range for the trench radio is 50 miles; that for the crystal receiver is 0.5 mile. Multiplying 50 × 0.5 gives 25, and the square root of 25 is 5; so their combined range is 5 miles.

Bandwidth

The development of communications technologies made *bandwidth* a key issue. Originally, it referred literally to a range of frequencies; for example, a transmitter tuned to 100,000 hertz might occupy frequencies from 97,000 to 103,000 hertz, a bandwidth of 6,000 hertz. Research showed that different frequencies could carry the same signal as long as they had the same bandwidth; for example, telephone circuits carried frequencies from 400 to 3,400 hertz (the main frequencies of the human voice), a difference of 3,000 hertz, and the same signal could be carried in the range from 30,000 to 33,000 hertz. Other research showed that *information* was proportional to bandwidth, which became important in the digital era as the basis of Claude Shannon's *information theory*.

Different types of signals have different bandwidths, suited to various human senses, and require different frequency ranges; see the table below.

Typical Bandwidths

Signal Type	*Bandwidth*
Telegraph	150 hertz
Telephone	3 kilohertz
High-fidelity audio	15 kilohertz
Fax	64 kilohertz
Television	6 megahertz
High-definition television	20 megahertz

Antennas

The standard ranges for radio communication assume a fairly small antenna, such as the whip antennas on classic walkie-talkies or car radios, or small loop antennas in TL6 AM radios. Other options offer greater range, by providing a longer active element or adding elements to produce a tight beam. This can be done at both the transmitting and receiving ends of a signal; if so, both multipliers apply.

In the UHF band (300 megahertz and up), antennas small enough to fit into a handheld radio can use the more efficient designs.

Quarter-Wave Monopole (TL6). Invented by Marconi during his first experiments. A vertical tower, equivalent to the long-range antenna in ***High-Tech,*** p. 39. Maximum range ×2 in a 360° circle. +25% cost and weight. 1895.

Half-Wave Dipole (TL6). Invented by Hertz. Two long wires strung horizontally in opposite directions. Maximum range ×1.5 perpendicular to the wires (to both sides); no signal goes out from the ends of the wires. A large *loop antenna* gives comparable performance. +10% cost and weight. [1887] 1900.

Directional Antenna (TL7). A variety of designs such as the Yagi antenna (the classic roof-mounted TV antenna) and the parabolic dish (as in microwave relays) that trade off breadth for range. Roll vs. Electronics Operation (Comm) to aim at a transmitter. Maximum range ×10 in a narrow beam pointing out from one side. At TL8, automatic aiming software can target a known transmitter such as a satellite. +50% cost and weight. [1888] 1940.

Spark-Gap Transmitters

Early transmitters use a spark gap (p. 10) to create electrical oscillations. This produces electromagnetic noise, like that from a static discharge such as lightning. Tuning is at best imprecise. A single spark doesn't last long enough to carry audio; spark-gap systems are used almost solely for wireless telegraphy. Shipboard radio operators in this era were often nicknamed "Sparks," a custom that long outlasted the actual use of spark gaps.

The following options apply to spark-gap radio. Multiply all cost factors together, and do the same for weight factors. All transmitters at this stage are large, and receivers are large or medium.

Coherer-Based: Receivers only. The signal flows through a tube of metal filings, making them stick together and conduct current from a battery. The standard system for early radio. Only able to detect code. [1894] 1895.

Crystal-Based: Receivers only. A fine-wire "cat's whisker" touching a crystal (typically carborundum or galena) turns radio signals into signals at audible frequencies. Roll vs. Electronics Operation (Comm) to find a sensitive spot; success gives +2 to Electronics Operation (Comm) rolls to receive a signal, failure gives -2, and critical failure prevents *any* reception. The signal is unamplified, with ×0.1 range, and the receiver requires no power. Improvised versions with scrounged parts were common as late as World War II. ×2 cost, ×0.75 weight. [1894] 1906.

Diode-Based: Receivers only. A diode vacuum tube turns radio signals into signals at audible frequencies. No skill roll required; no bonus or penalty to rolls to receive a signal. The signal is unamplified, with ×0.1 range; power is used only to heat the diode's filament. M/14 hours. ×2 cost. 1904.

Receive-Only: A radio receiver as a separate unit. Mutually exclusive with "send-only"; every spark-gap radio must have one or the other. ×0.1 cost, ×0.2 weight.

Rotary Spark Gap: Transmitters only. Gives a steadier output, typically producing 120 sparks per second; +1 (quality) to Electronics Operation (Comm). ×5 cost. An ultra-high-speed version gives +2 (quality) to Electronics Operation (Comm) and can be used to send audio (see *New Radio Option,* p. 32); however, the signal suffers from severe distortion, giving -5 to rolls to *understand* speech, and to Connoisseur (Music) rolls. ×20 cost.

Send-Only: A radio transmitter as a separate unit. Mutually exclusive with "receive-only"; every spark-gap radio must have one or the other. ×0.9 cost, ×0.9 weight.

Wideband: Transmitters only; required for spark-gap systems. Tuning is inherently imprecise; to avoid interference, frequency settings have to be widely spaced. Transmitter bandwidth is much greater than required (*Bandwidth,* p. 28), but most of it is taken up by the noise the transmitter generates. Power consumption is high; batteries last one-fifth as long. ×1.25 weight.

Trench Radio (TL6)

Radio equipment designed for use under battlefield conditions in World War I. It contains the following components:

- A spark-gap radio transmitter operating at 350 meters (857 kilohertz), 450 meters (667 kilohertz), 550 meters (545 kilohertz), and the international distress wavelength of 600 meters (500 kilohertz). Large, send-only (above), wideband (above). Range 50 miles. Includes three lead-acid M batteries that supply power for 35 minutes. $1,575, 112.5 lbs.
- A crystal-based (p. 28) receiver. Medium, receive-only (p. 28). Range 0.5 miles. $250, 4.5 lbs.
- Insulated wire for a dipole antenna (p. 28). Gives ×1.5 range. An improvised "ground aerial" made of two lengths of wire running in opposite directions gives -2 to Electronics Operation (Comm) but is concealable with a Camouflage roll. A reel of 1,000' of wire is $300, 75 lbs.
- Half a dozen sets of spare batteries. $84, 24 lbs.

Oscillators

Early in the 20th century, radio experimenters developed methods of sustaining radio-frequency oscillations in a transmitter. The resulting *continuous waves* could be tuned to a precise frequency, avoiding the problems of wideband transmission (above); their bandwidth was no greater than the content required (p. 28). Content could be audio (or, later, video), as well as code, by *modulating* the signal (*Audio,* pp. 30-33; *Video,* pp. 33-34). In 1920, spark-gap transmitters were internationally outlawed as sources of interference.

Two basic strategies were tried for producing continued oscillation. One was *direct:* running an alternator (below) at high enough speed to produce radio-frequency current. The other was *indirect:* feeding electrical energy into a tuned circuit, like those in Marconi's transmitters, to keep it oscillating steadily. Tuned circuits based on coils and capacitors suffer frequency drift and require Electronics Operation (Comm) rolls by the listener every 10 minutes. Circuits based on quartz crystals (available from 1921 on) make this unnecessary and give more precise tuning; treat them as cutting edge (p. 8) at TL6.

Transmitters

Arc Converter (TL6). An early form of tuned-circuit oscillator, in which electric arcs sustain the oscillation; used for large, high-power transmitters into the 1920s. On a critical failure, it creates interference at multiples of its frequency. Treat as a standard Large transmitter. Average complexity. [1903].

Alternator (TL6). A specialized generator spinning at thousands of RPM. A small model is stationary (weighing several tons) and consumes 7.5 gallons of hydrocarbon fuel per hour. Its high power allows a 200-mile range. Requires a skilled mechanic to keep it running (roll daily vs. Mechanic for the power-plant type). If it breaks down, minor repairs (p. B484) can restart it. Most alternators operate at 10-30 kilohertz; high-quality models can reach hundreds of kilohertz. Tuning is highly stable (equivalent to a quartz-crystal system). Changing the frequency requires a full day's work. Complex complexity. [1904] 1911. Obsolete by 1920, but the last transmitters were shut down in 1958 and 1960.

Electronic Oscillator (TL6). Uses a vacuum-tube amplifier (see *Audio Amplification,* p. 32) to provide feedback to a tuned circuit. Radios with electronic oscillators often both receive and transmit; receive-only (p. 28) and send-only (above) are optional. Vacuum-tube radios can be large, medium, or small. Transistors (p. 5) allow radios to be tiny. [1912] 1920.

Tuning In

Spark-gap radios offer only a few frequencies, chosen by a switch; no skill roll is required to select one. The development of oscillators led to receivers that could be scanned across the radio spectrum. This can require a *tuning roll* against Electronics Operation (Comm) to pick up a faint signal, or to avoid interference. Tuning rolls take several modifiers: -1 per 10% by which the distance to the transmitter exceeds the standard range (*Mix and Match,* p. 28); -1 to -10 for interference (see *Radios,* pp. 27-28), or +1 to +4 for favorable conditions; any modifiers to Hearing rolls (p. B358); +4 for a radio with enhanced tuning (*Software-Defined Radio,* p. 30).

Connecting a galvanometer (pp. 10-11) to a radio to monitor signal strength – which requires a roll vs. Electronics Repair (Comm) – gives +1 to this roll *in place of* Hearing modifiers; an expensive radio may have meters built in (treat as a quality modifier).

Electronic Receivers

Grid-Leak: An option for audio receivers, in which the same tube acts both as a detector and an (inefficient) amplifier. Divide receiver range by 5. [1906] 1915.

Regenerative: An option for audio receivers, in which an amplified output is fed back to the input circuit, producing higher gain. Requires adjustment with an Electronics Operation (Comm) roll. On a failure, divide receiver range by 5. On a critical failure, the receiver oscillates; no signal is received, and other receivers within 440 yards suffer -4 to reception from interference (reduce the penalty by 1 for each ×2 range). [1913] 1920.

Superheterodyne: An option for audio receivers, and standard in video receivers; a sophisticated design with multiple tubes provides stable reception that requires minimal tuning adjustments with a simple Hearing roll, and enough power to support a loudspeaker. [1918] 1930. After 1940 (TL7), a five-tube model was standard for audio. Transistor versions appeared in 1954.

Shortwave Radio (TL6)

Radio waves at frequencies from 1.5 to 30 megahertz can "skip" off the upper atmosphere. One skip can reach up to 2,000 miles; each additional skip gives -1 to Electronics Operation (Comm) – six skips (-5) can pick up a transmission from anywhere on Earth. A large antenna (p. 28) is necessary for transmission. Apply -2 for each of unfavorable time of day (day for 1.5-12 megahertz, night for 12-30 megahertz), summer, and solar flares. Cost and weight are unchanged, but transmitter and receiver must both be shortwave. [1921] 1924.

Software-Defined Radio

As computer speeds increased (see p. 36), it became possible to analyze and synthesize radio-frequency signals digitally, one cycle at a time, in what became known as *software-defined radio*. With suitable software and peripherals, a computer could take the place of a radio transceiver. Two such computers can function in a *cognitive radio* mode, giving them the benefits of *spread-spectrum* transmission (pp. 46-47).

Radio Peripheral (TL8). A combination of analog-to-digital and digital-to-analog converters that works directly with radio signals. Allows a computer to emulate multiple types of radio, sending and receiving data, text, audio, and sometimes still pictures. In addition to enhanced tuning (*Tuning In,* p. 29), the user can record a radio signal directly by making a Computer Operation roll and then recognize it or search for it later. 35-mile range. Household power. $600, 2.5 lbs. [1984] 1988.

Digital TV Tuner (TL8). A small peripheral device that provides a computer with the ability to receive digital broadcast television, but doesn't function as a transmitter. Can be adapted into a general-purpose radio peripheral with downloaded software and a Computer Operation roll. Its lower sensitivity gives no bonus to Electronics Operation (Comm) rolls. Peripheral power. $20, neg. 2009.

Optical

Another way to send signals is on beams of light, directed at photoelectric sensors to produce varying current flow. Such beams can be more directional than radio. Early versions used reflected sunlight; this was followed by communicators based on arc lights (p. 20), and much later, on lasers (p. 5). After the development of *optical fiber* in 1970, fiber-optic communication came into commercial use in the 1980s, increasingly replacing wire-based signals throughout TL8. Roll vs. Electronics Operation (Comm), except for devices using optical fiber, which usually require no skill roll.

Photophone (TL6). A prototype using reflected sunlight to carry audio signals to a parabolic mirror (1' in diameter), photocell, and earphone at a range of 250 yards. Requires full daylight (10,000 lux); powered by half a dozen M wet cells (pp. 16-17). Average complexity. [1880].

Communications Satellites

In 1945, Arthur C. Clarke proposed that satellites in geostationary orbits (at an altitude where they would take 24 hours to orbit the Earth, maintaining a fixed longitude) could be used to relay radio communications. Experimental satellite relays were launched starting in 1960. By 1965, commercial communications satellites came into service. They initially served telecommunications industries such as telephony and television, but TL8 saw the emergence of personally owned devices that could access satellite communications, such as phones and dishes for television reception. After 2000, lower-altitude satellites allowed satellite phones (discussed in ***High-Tech,*** pp. 39-40) to shrink to the size of a bulky cell phone. Satellite phone reception is poor indoors: roll vs. Electronics Operation (Comm) at -5 to communicate – but there's no penalty to simply page a phone.

Satellite Phone Repeater (TL8)

An outdoor satellite-phone transceiver and antenna, connected to an indoor transceiver and antenna by a cable. Avoids penalties for using the phone indoors, inside a ship's hull, and even underground at up to a 2-mile range. Household power. $22,500, 10 lbs. 2000.

Audio

Audio technology goes back to the telephone (pp. 26-27). Vacuum-tube amplification was applied to long-distance calls in 1915 and to sound recording in 1925. After World War II (TL7), more sophisticated electronics made better sound reproduction possible. This lead to the emergence of *high fidelity* as a market and as a hobby (see p. 7), in which sound systems were assembled from separate components of good or fine quality. Such systems commonly included innovative technologies such as FM receivers and tape recorders – and later, stereophonic sound, introduced in 1957. Digital sound emerged in 1982 and quickly became dominant, though many audiophiles still use analog technologies such as vinyl.

Roll vs. Electronics Operation (Media) to use audio equipment professionally, or Hobby Skill (High Fidelity) to use sophisticated home systems or to build components from kits (see *Heathkit,* p. 15).

Audio Transducers

Sound was one of the first forms of energy for which transducers were developed (*Transducers and Meters,* pp. 12-13).

Microphones

Microphones convert sound into electrical signals, usually with a solid element moved by sound pressure. Experimental versions in 1876 were followed in 1877 by the *carbon microphone,* the first really successful form. Later types included the *condenser microphone* in 1916 and the *moving coil microphone* in 1923, both of which gave higher signal quality (+1 to Electronics Operation rolls; if high-fidelity sound is needed, treat them as basic equipment, and carbon microphones as improvised equipment giving -5 to sound quality). However, carbon microphones are resistant to damage (HT 12 vs. HT 10).

Microphone (TL6). A basic transducer that converts sound to audio-frequency signals. Inexpensive versions with lower signal quality are available at 20% of the price. $100, 3 lbs. [1876] 1877.

Hydrophone (TL6). A microphone designed to work underwater, typically mounted on the side of a ship, first invented after the sinking of the *Titanic;* also called "passive sonar." This is a basic design not intended for tactical use. Roll vs. Electronics Operation (Sonar) to hear an underwater sound, at +2 at TL7 or +4 at TL8. To detect a moving object, apply a bonus for size, a bonus for speed, and a penalty for range per the *Size and Speed/Range Table* (p. B550). Automotive or household power. $500, 15 lbs. [1912] 1918.

Parabolic Microphone (TL6). A microphone mounted at the focus of a parabolic surface. It must be targeted on the sound source (roll vs. Electronics Operation with any applicable Hearing modifiers), but once targeted, gives +2 to detect or identify sounds. A 1-yard-diameter reflector works for sounds at 1 kilohertz or higher, such as bird songs; halve the bonus for human speech, and ignore it for lower-pitched sounds. $300, 5 lbs.

Throat Microphone (TL6). A microphone in physical contact with the throat. Originally used by pilots to speak without interference from aircraft noise. $150, 0.5 lb. 1934.

Shotgun Microphone (TL7). Invented in the movie industry for use on sound stages – but adventurers will think of other uses! Responds much more strongly to sounds directly in front of it than to sounds from other directions, giving +3 to Electronics Operation rolls to target a specific sound. $150, 3 lbs.

Microphone (TL8). A compact microphone using miniaturized components. $50, 1 lb.

Parabolic Microphone (TL8). A compact device using miniaturized components. $250, 2 lbs.

Shotgun Microphone (TL8). A compact device using miniaturized components. $75, 1 lb.

Throat Microphone (TL8). A compact device using miniaturized components. $150, neg.

I'm sending you
out this signal here
– Joni Mitchell,
"You Turn Me On,
I'm a Radio"

Earphones and Speakers

Earphones and speakers convert electrical signals into sound. Most such devices can also be adapted for use as microphones at -2 (quality). The first version capable of reproducing speech understandably was a moving-iron design where a stationary coil vibrated a metal diaphragm magnetically; telephones came with one each. Moving-coil designs were invented later and quickly became standard because of superior sound quality. Stereophonic sound requires at least two earphones or speakers.

Quality modifiers apply to Hearing rolls intended to discriminate sounds and to Connoisseur (Music) rolls. However, the quality bonus is limited by the signal source; a cheap microphone, a low-bandwidth circuit such as a telephone line, or an inexpensive amplifier won't sound any better with superior earphones or speakers.

Users of headphones are effectively Hard of Hearing while listening as a result of interference. Reduce the penalty to -2 if they turn the sound down but leave it on, as they are trying to do two things at once.

Headphones (TL6). A pair of earphones mounted in earpieces, providing basic quality sound. Early models are connected directly to the high-voltage output of a vacuum-tube amplifier (see *Audio Amplification,* p. 32) and may shock the user if handled carelessly. $50, 1.5 lb. [1910] 1924.

Loudspeaker (TL6). The now standard version was invented after the moving-coil system was created; it has a coil attached to a paper cone that gives enough sound to fill a room. Higher quality requires multiple speakers and more substantial housings; multiply weight ×2 for each step of quality improvement. $20, 3 lbs. 1924.

Earbuds (TL7). First developed for use in hearing aids (p. 32), small earphones (called *earbuds* since 1984) were adapted to use with consumer devices. They don't exclude external sound as well as headphones; subtract one-half the penalty for external noise when making Hearing-based rolls. $13, neg. 1954.

Stereo Headphones (TL7). Higher-quality stereo headphones. $60, 0.5 lb. 1958.

Tactical Headset (TL8). Combines a throat microphone that screens out background noise with noise-canceling headphones that provide Protected Hearing (p. B878). $200, 1 lb. [1986] 1989.

Wireless Headphones (TL8). Headphones capable of noise cancellation and of wireless interfacing with a computer or digital music player. $45, 0.5 lb. 2000.

Audio Generation

Audio-frequency circuits that generate waveforms to be output as sound include various electronic musical instruments; see also *Signal Generators and Tracers* (p. 11). Some are played with Musical Instrument (Keyboard); others, with unique skills (p. 7).

Electric Organ (TL6). A keyboard instrument with tonewheels (rotating magnetized disks with electromagnetic pickups), whose output could be combined to produce a complex waveform imitating that of a musical instrument. The first such instrument, the *telharmonium,* consumed 670 kilowatts, weighed 200 tons, and was used primarily to send music over telephone lines (in 1906, Lee de Forest made experimental broadcasts with an arc converter); treat it as a Complex complexity prototype. The technology became commercial with the *Hammond organ*. Household power. $2,700, 425 lbs. [1896] 1935.

Singing Arc (TL6). A prototype keyboard instrument based on the discovery that an electric arc could sustain oscillation in a tuned circuit (see *Arc Converter,* p. 29). Roll vs. Electrician or Physics to set up, and Musical Instrument (Keyboard) to play. Average complexity. Household power. [1900].

Theremin (TL6). An analog musical instrument, named for its inventor. Controlled by body capacitance, with one hand changing the pitch and the other the volume; roll vs. Musical Instrument (Theremin) to play. Household power. $240, 4 lbs. [1928] 1930.

Electronic Organ (TL7). A compact keyboard instrument with vacuum tube or transistor circuits. Household power. $1,100, 200 lbs. [1940] 1949.

Stylophone (TL7). An analog instrument with a printed circuit grid touched with a stylus to turn on oscillation at a particular frequency – roll vs. Musical Instrument (Stylophone) to play. Notably played by David Bowie on "Space Oddity." 2×XS/8 hours. $35, 0.6 lb. 1967.

Synthesizer (TL7). A transistor-based keyboard instrument in which analog circuits produce a variety of waveforms and sound qualities; widely used in progressive rock after the Monterey Pop Festival. A compact version, the Minimoog, became available in 1970. Roll vs. Electronics Operation (Media) to design sound qualities. Household power. $3,300, 37.5 lbs. [1964] 1970.

Synthesizer (TL8). A programmable digital keyboard instrument. Household power. $3,750, 40 lbs. [1979] 1983.

Audio Amplification

The function of many audio circuits is amplify a faint sound into a larger one, using vacuum tubes (p. 5) or transistors (p. 5). Many radio receivers incorporate amplifiers and can power a loudspeaker (p. 31).

Public Address System (TL6). A microphone to pick up sound and one or more loudspeakers to output it at amplified volume. Early models use batteries and carbon microphones, giving -2 to sound quality; the mature technology uses electronic amplification. Base hearing range 16 yards. Automotive power, household power, or L/40 hours. $150, 15 lbs.; add $20 and 3 lbs. per extra speaker, and divide battery life by number of speakers. [1910] 1919.

Guitar Amplifier (TL6). Early improvised guitar amplifiers attached microphones to conventional guitars, feeding into PA systems; roll vs. Electronics Operation (Media) to set up. Sound quality is at -2. Special-purpose pickups and amplifiers can be used with no penalty. Base Hearing range 16 yards. Musical experimentation with distortion began in the 1950s, at -2 to effective skill. Household power; can be adapted to automotive power with a roll vs. Electronics Repair (Media). $150, 15 lbs. [1927] 1932.

Hearing Aid (TL6). A Mitigator for Hard of Hearing (p. B138). Gives up to +4 to Hearing rolls, canceling the -4 for Hard of Hearing, but a Hearing roll is still required. Early experimental versions used batteries and carbon microphones; sound quality was low, giving -2 to Hearing rolls. Vacuum-tube versions avoided this issue, and could be carried in a briefcase or large purse. 2×M/1 month. 7 lbs., $1,200. [1898] 1923.

Hearing Aid (TL7). Advances in vacuum tubes during World War II, and then the invention of the transistor, made pocket-sized hearing aids practical. XS/3 months. 0.5 lb., $1,200. [1936] 1948.

Bullhorn (TL7). Handheld electric megaphones become practical after the invention of the transistor. They have a microphone, a horn speaker, and a switch in a pistol grip. Base Hearing range is 16 yards to the front, 8 yards to the side, and 4 yards to the rear. Sound output is distorted, giving -2 to rolls to recognize a voice or understand speech. Gives +1 to Intimidation out to 2 yards to the front or 1 yard to the side. 8×S/4 hours. $30, 4.5 lbs. 1954.

Guitar Amplifier (TL7). A higher-powered amplifier with no extra penalty to create distortion. Base Hearing range 32 yards. Household power. $260, 40 lbs. 1961.

Hearing Aid (TL8). Microprocessors led to the development of digital hearing aids; early versions were no smaller, but the mature versions could be worn behind the ear. T/3 months. $1,200, neg. [1982] 1989.

Acoustic Hailing Device (TL8). An extremely high-powered sound amplifier. Base Hearing range is 256 yards in a 60° cone to the front. Advanced signal processing keeps its sound output intelligible at full range. Gives +1 to Intimidation out to 32 yards. Can be applied as a nonlethal weapon (see p. 51). Rechargeable/8 hours or automotive power. $15,000, 15 lbs. 2002.

Guitar Amplifier (TL8). A solid-state amplifier. Much less heavy, but many players prefer the sound quality of tube amplifiers. Household power. $130, 16 lbs. 1980.

Audio Transmission and Reception

Modulation imposes a lower-frequency signal on higher-frequency radio waves (*Bandwidth,* p. 28). Audio transmitters modulate radio waves to carry audio signals, and audio receivers extract the signals. Under nonroutine conditions, roll vs. Electronics Operation (Comm) to operate a low-fidelity receiver, or vs. Electronics Operation (Comm or Media) or Hobby Skill (High Fidelity) for a high-fidelity one.

Originally, transmitters used *amplitude modulation,* in which the strength of the radio wave varies with the sound wave. This is subject to interference from static (*Tuning In,* p. 29).

Frequency modulation (TL7; [1933] 1941) – in which the frequency of the radio wave varies – is unaffected by static, but another signal of equal or greater strength on the same frequency totally prevents reception. At TL7, FM is cutting edge (p. 8) and used for high-fidelity systems (see p. 30). At TL8, it's more common than AM and costs no more.

New Radio Option

An early experiment used a carbon microphone to modulate an ultra-high-speed rotary spark-gap transmitter (10,000 sparks per second; see p. 28); treat such a device as improvised equipment giving -5 to Electronics Operation (Comm) because of a noisy signal. Basic and higher quality devices become available with sustained oscillations (*Oscillators,* p. 29). This provides the following new option for radios.

Audio: The circuits can transmit or detect signals modulated with audio. Most such devices have built-in microphones, earphones, and/or speakers. ×2 cost. [1903] 1914.

Audio Recording

Electronic sound recording stores an electrical signal generated by sound on some durable medium. This grew out of amplifiers that could provide a strong signal. Several different technologies have been used. See ***High-Tech,*** p. 42, for media.

Phonograph (TL6). In electronic phonographs, the needle affects a *pickup*, which feeds into an amplifier. Early models have heavy magnetic pickups whose full weight rests on the record, causing rapid deterioration. Counterweighted arms and smaller pickups, magnetic or piezoelectric, avoid this problem. $70, 7 lbs. [1925] 1935.

Dictation Machine (TL7). Uses a microphone and amplifier to cut grooves into a wax cylinder. $460, 10 lbs. 1939.

Reel-to-Reel Tape Recorder (TL7). A device for recording sound on magnetic tape, and playing it back. Early experimental German versions produced significant distortion; -2 to Electronics Operation (Media) and rolls based on sound quality. A technique for eliminating it was discovered in 1939 and was included in commercially produced American models. Household power. $150, 10 lbs. [1928] 1947.

Answering Machine (TL7). An electromechanical or magnetic recording device for telephone calls. Typically, it delivers a greeting and then records a message. At TL8, its function is often incorporated into a telephone. Household power. $150, 10 lbs. [1929] 1949.

Cassette Recorder (TL7). A tape recorder using compact magnetic tape cassettes, offering improved portability at the expense of sound quality; good and fine quality are unavailable with narrow cassette tapes. 5×S/8 hours. $150, 3 lbs. 1963.

Dictation Machine (TL7). Records on reusable magnetic cassettes. Household power. $300, 5 lbs. 1963.

Personal Cassette Player (TL8). A pocket-sized play-only device designed to be used with headphones, such as Sony's Walkman, which created the market for personally chosen music. XS/36 hours. $100, 0.5 lb. 1979.

CD Player (TL8). A device that plays music or other sounds from digital files on an optical disk. 2×XS/75 hours or rechargeable/75 hours. $25, 0.5 lb. 1983.

Digital Music Player (TL8). A tiny device such as Apple's iPod, able to store hundreds or thousands of songs or other audio in digital form, and output them to headphones. Content is downloaded from a computer. More advanced models can store and display video and perform a variety of other functions. Similar functions are incorporated into smartphones. T/7 hours. $225, neg. 2001.

Digital Voice Recorder (TL8). A pocket-sized device that can record sound in digital form and later play it back or upload it to a computer. Its memory capacity is sufficient for 1,500 hours of sound. Concealable with an unmodified Holdout roll, making it useful for spies! Peripheral power or recharge/10 hours. $50, neg. 2001.

Video

Transmission of images began with still pictures sent over telegraph lines, scanned using selenium photocells. Experiments with rapidly repeated scanning in the early 20th century made it possible to transmit moving images. Electronic scanning based on *cathode-ray tubes* (CRTs), which scan an electron beam over a photoelectric screen, led to commercial television in the 1940s. Digital video, developed in the 1990s, allowed higher-definition images and largely replaced analog video by 2010.

Use Photography to capture still images, or Photography-3 to capture moving ones (for either live transmission or recording); digital cameras, or devices such as smartphones, may incorporate software that takes routine photographs with no skill roll (treat as improvised equipment for challenging photos that require a Photography roll). Processing or editing images is Electronics Operation (Media).

Scanners and Printers

A scanner turns a still image into a series of electrical impulses, either analog or digital. Such a signal can be output to a printer.

Scanner (TL7). A device for turning an image on a sheet of paper or transparent material into a signal that can be output to a computer for storage. The sheet is placed on a drum that rotates past an array of photomultiplier tubes. Household power. $20,000, 85 lbs. 1957.

Flatbed Scanner (TL8). Available after the development of solid-state image devices. Captures documents easily but give -2 (quality) to Electronics Operation (Media) to capture images of high artistic quality, or photographs that need to be enlarged. Household power. $75, 9 lbs. [1985] 1995.

Laser Printer (TL8). Adapts the principle of xerography from photocopying to printing original images drawn with laser beams under computer control. High resolution gives +1 (quality) to Artist rolls. Invented in 1972; commercially available in 1976, but only in expensive, stationary high-volume models. Household power. $150; 35 lbs. 1984.

Cameras and Displays

Video cameras work much faster than scanners, 50 or 60 images per second (matching the power-line frequency in Europe or the United States) – fast enough to create the illusion of a moving image rather than flickering still pictures. Video displays can show images at the same rate.

Monitor (TL7). A CRT-based display for a video signal from a television camera, video recorder, or computer. At TL7, early home computer systems are designed to be connected to small television sets; this is straightforward and doesn't impose a penalty on Computer Operation. Color monitors become available in 1954 as cutting-edge equipment (see p. 8). At TL8, color is standard. Household power. $450, 25 lbs. [1922] 1941.

Television Camera (TL7). Early experimental television cameras used mechanical scanners that produced 15-20 frames per second with very low definition, giving -5 to Vision rolls. CRTs emerged as an alternative in the late 1920s and became the standard technology. Color cameras appeared in 1954. Major appliance power. $5,000, stationary. [1925] 1941.

Compact Monitor (TL7). Available after 1970. $100, 12.5 lbs.

Flatscreen Monitor (TL8). Technologies such as LCD, plasma, and LED almost completely replace CRTs by the mid-2000s. Treat as cutting edge (p. 8) before 2000. Household power. $90, 7 lbs. 1986.

Digital Micromirror Device (TL8). A projection system that fits several hundred thousand microscopic mirrors onto a MEMS chip (p. 24) a few inches on a side, each of which can direct light from an external source into a lens. Early models used arc lights; since 2008, high-powered LEDs or lasers in multiple colors have replaced them. Widely used in digital cinema and other projection devices. [1987] 1999. Available in various sizes:

Mini Projector: Projects the image from the screen of a smartphone or tablet onto a flat surface up to 10' away (maximum virtual screen size 130"). Rechargeable/3 hours. $150, 0.75 lb.

Home Theater Projector: Projects video output onto a screen up to 200". Automotive power/household power. $375, 2 lbs.

Webcam (TL8). A very small camera and microphone designed to feed into a computer, usually for uploading to the Internet, or to upload to a wired or wireless channel. Often built into computers or other devices. Peripheral power. $10, neg. Professional models with +1 (quality) to skill are available. $50, 0.5 lb.

Video Transmission and Reception

Video signals can modulate radio waves in much the same way as audio, but have much higher bandwidth (*Bandwidth,* p. 28) and can only be carried by high frequencies, 50 megahertz and above. This technology provides new options for radio systems:

Video (TL7). Can transmit and/or receive signals modulated with video, using vacuum tubes or transistors for amplification. Video systems commonly carry audio as well; the extra bandwidth is hardly noticeable. Normally they *either* transmit or receive, but not both. Vacuum-tube systems are based on large or medium radios. [1928] 1941. Transistor systems can be based on small radios. [1952] 1960. ×4 cost, ×2 weight.

Digital Video (TL8). Can be based on small or tiny radios. Most such systems provide high-definition images. [1996] 2009. ×4 cost, ×2 weight.

Video transmitters don't include cameras or displays. These are bought separately, and the two systems are connected. However, video receivers are almost always packaged with displays as *television sets*. Originally, they were used to receive broadcasts; the advent of cable in 1950 (originally to supply amplified broadcast signals to viewers with poor reception) and its partial deregulation in 1972 led to a situation where the majority of television sets are connected to cable systems. A small percentage of viewers use antennas or satellite receivers instead.

Console Television (TL7). A commercially manufactured receiver for home viewing in black and white. Cutting edge (p. 8) through the end of World War II. $1,400, 60 lbs. [1926] 1938.

Tabletop Television (TL7). A smaller receiver. Household power. $1,050, 33 lbs. 1946.

Color Television (TL7). Cutting edge at TL7. Household power. Household power. This device is priced as cutting-edge at TL7: $1,400, 60 lbs. [1926] 1953. At TL8, the cost is $280.

Portable Television (TL7). Transistor-based models were more affordable and convenient and came into widespread use. Often adapted as improvised monitors for home computers (pp. 36-38). Has a color display at TL8. Household power. $180, 13 lbs. [1953] 1970.

Flatscreen Television (TL8). A freestanding television receiver with up to a 32" LCD or LED screen. Wall-mounted models up to 64" average 5× the cost and weight; larger models average 20× the cost and weight. $130, 7 lbs. [1958] 2006.

Converter Box (TL8). A small device that takes in a broadcast digital TV signal and outputs an analog signal for an older television. Household power. $40, 0.3 lb. 2009.

Video Recording

Recording video was originally done on magnetic tape; experiments began in the 1950s. See ***High-Tech,*** p. 44, for details about storage media not described here. Digital video led to the use of digital storage media; by 2000, videotape was falling out of use.

Videotape Recorder (TL7). A device for recording television programs, playing them back, and playing purchased videocassettes. The Betamax format (available in 1975) was limited to 60 minutes. The VHS format (available after 1976 in Japan and 1977 in the United States) held 2-3 hours and decisively displaced Betamax between 1981 and 1986. Videocassettes cost $2, weigh 0.5 lb. Household power. $150, 8 lbs. [1972] 1975.

Camcorder (TL8). A camera that stores moving pictures on 0.5" magnetic tape as an analog signal, used by television news programs and serious hobbyists. Can record up to 90 minutes of video. M/2 hours. $1,500, 8 lbs. 1983.

Compact Camcorder (TL8). A smaller model using 8-mm tape. M/3 hours. $1,500, 2 lbs. 1985.

Digital Camera (TL8). An electronic device that can take still pictures, store them, and transmit them to a computer or printer. Many can also record moving pictures. XS/12 hours. $65. [1975] 1995.

DVD Player (TL8). A player for digital versatile disks. Household power. $80, 10 lbs. 1997. DVDs cost $2, have negligible weight, and hold 133 minutes of content or 4.7 GB of data; after 2007, 240 minutes of content or 8.5 GB of data.

Digital Video Recorder (TL8). Records digital video content in a solid-state medium and plays it back. A computer with a suitable adapter and software can function as a DVR; each hour of content requires 1 GB of storage. Household power. $100, 6 lbs. 1999.

Blu-Ray Player (TL8). Uses shorter-wavelength blue light for higher resolution and more data capacity (50 GB is the industry standard). Initially priced as cutting-edge equipment (see p. 8). Household power. $80, 2.5 lbs. [2000] 2006.

Digital Camcorder (TL8). Early models used 0.75" tape or DVDs, but they didn't become successful until they adopted solid-state memory. Rechargeable/1 hour. $100, 1.5 lbs. [1986] 2006. Professional models give +1 (quality) to Electronics Operation (Media). Rechargeable/90 minutes. $500, 8 lbs. 2006.

Active Rangefinding

Devices for sensing objects at a distance were largely products of military research; see *Surveillance and Countersurveillance* (pp. 45-46) and *Alarms* (pp. 43-44). Active detection systems send out energy of various kinds – high-frequency sound, radio waves, and (later) laser beams – and pick up reflected energy.

The energy emitted by active rangefinding gear can be detected at twice the sensor's range. This can be increased by a skill roll at -1 per additional 20% of the sensor's range, out to a maximum of -10 for an additional 200%.

The size of the target affects target detection. Apply a bonus or penalty to operator skill equal to half the target's SM, rounded down.

A skilled operator, using Electronics Operation (Sensors or Sonar), can enhance the performance of rangefinding gear. A sensor operator can detect targets more distant than the rated range with a roll at -2 per *doubling* of range (-1 for a half-level increase giving ×1.5 range). This penalty can be avoided by focusing longer on a target (×4 for doubled range, or ×15 for quadrupled range) and thus sending out proportionally more impulses; however, this gives the target a bonus to detect the emissions (+2 or +4).

For more active-rangefinding equipment, see ***High-Tech,*** pp. 45-47.

Devices for sensing objects at a distance were largely products of military research.

Sonar

Sound was initially used to locate submerged objects. Research began almost immediately after the sinking of the *Titanic* in 1912. Within two years, experimental devices had been invented in Britain, Germany, and the United States. Prototype systems for detecting submarines were created by 1918, and sonar came into full use during World War II (TL7). Wearing headphones as well as viewing a screen gives +1 to rolls to interpret sonar readings.

Standard sonar uses kilohertz frequencies; in water, its resolution ranges from 3" to 1/10". Imaging sonar, as in medical ultrasound and industrial materials testing, relies on low megahertz frequencies, achieving a resolution from 1/16" to 1/300".

Echo Sounder (TL6). A ship-mounted device that uses sonar to measure the depth under the hull. Gives warning of submerged hazards and can be compared with charts of known depths. Household power. $600; 10 lbs. 1913.

Echo Sounder (TL8). A digital system that can store mapping data and display maps on a screen.

Handheld Sonar (TL8). A handheld device that produces sonar images of underwater objects, terrain, and life forms, with a resolution of 1/10". Range is 10 yards. 8×S/20 hours. $10,000, 16 lbs.

Radar

Shortly after discovering radio waves, Hertz demonstrated experimentally that they could be reflected from solid objects. By 1935, radar systems for aircraft detection were being tested in a number of countries.

Radar uses a number of frequency bands. Higher frequencies have shorter wavelengths and can detect smaller objects and features. Wavelengths longer than a foot are used for special purposes such as ground penetration. Standard radar operates at wavelengths measured in centimeters, from an inch to a foot, and can detect vehicles, human beings, and other large animals, but not identify what they are. Millimeter-wave radar has imaging capabilities, though its resolution is coarser than that of human vision.

Radar Gun (TL7). A device that applies radar to measure speed, primarily used by police forces to detect speeders. Measures vehicle speed to the nearest Move rating by frequency changes in reflected waves caused by the Doppler effect. Automotive power. $500, 4.5 lbs. [1947] 1954.

Ground-Penetrating Radar (TL7). A radar set using comparatively low frequencies that can penetrate soil and rock, mounted on a tricycle base for maneuverability, with two different antennas for low and high frequencies. Low frequencies (30-300 megahertz) penetrate to 10-50 yards, with image resolution 1-10 yards. High frequencies (300-1,000 megahertz) penetrate to 0-10 yards, with image resolution 1-3 feet. Has a variety of uses, from archaeological studies or treasure hunting, to prospecting and engineering, to finding military threats. Roll vs. Electronics Operation (Scientific) to gain +2 to a relevant skill. Rechargeable/8 hours. $9,500, 77 lbs. [1910] 1975.

Radar Gun (TL8). A digital version with a numerical readout. Automotive power. $500, 2.25 lbs.

Celldar (TL8). A passive variant on radar, using microwave emissions from cell-phone towers. Requires analog-to-digital conversion and a dedicated computer of Complexity 3; an improvised version can be created from two or more cell phones and a laptop computer. Variant systems can be based on other transmitters in microwave-frequency bands, such as FM radio. Such systems are hard to spot, since they don't emit radar frequencies, and conventional radar jamming and stealth are ineffective against them. Average complexity. Rechargeable/10 hours. [1999].

Lidar

One of the first uses of lasers was measurement of ranges to objects – including the moon, as early as 1962! Observations of atmospheric scattering led to the use of lasers in meteorological research. Many other applications have been developed since then.

Laser Measuring Tool (TL8). A handheld device that bounces laser beams off of surfaces to measure the dimensions of rooms and other spaces, up to 100 yards. Results are displayed on a digital readout and can include calculated areas, volumes, and diagonal dimensions. Gives +1 to effective skill for Cartography, Engineer, or other tasks that involve measurement. XS/10,000 readings. $50, 0.25 lb. 1993.

Chapter Five
Computation

Computers and related devices use *digital electronics,* in which electronic circuits operate at a fixed number of distinct voltage levels – usually two, defined as "ON" and "OFF." Such circuits can represent *binary* or *base 2* numbers (1 for "one," 10 for "two," 11 for "three," and so on) or "True" and "False" in mathematical logic, developed by George Boole in 1847. C.S. Peirce proposed the use of electrical switches to represent expressions in Boolean algebra in 1886. Almost all actual digital logic systems use *electronic switches* (see *Switching,* pp. 24-25) in various forms.

For an overview of terms used in equipment descriptions, see *Understanding the Devices,* pp. 8-9.

Computers

Computers were the first digital devices to be made practical. Despite the name, "computers" do more than calculate; they can carry out any step-by-step procedure for symbol manipulation, no matter what the symbols represent. Such procedures, or *algorithms,* are the basis of *sequential logic,* in which each step relies on results of earlier steps. Many of the earliest computers were used in World War II to break German and Japanese codes.

Running a computer uses Computer Operation skill.

Processing Power

Different computers can run more or less complex programs (*Programs and Languages,* p. 38). In ***GURPS,*** the measure of a computer's processing power is its *Complexity* (p. B472). This is also a measure of how difficult a program is to run. A typical computer can run two programs of its own Complexity, or trade off one program of any Complexity for 10 programs with Complexity one step less.

Logic

The heart of a computer is the *central processing unit (CPU),* where the instructions of programs are interpreted and carried out. Most CPUs do this at a pace set by an external oscillator, the *clock*. Typical clock speeds were 10 hertz for relay-based computers, 10 kilohertz for vacuum-tube designs, 1 megahertz for transistor designs and early integrated circuits, and 100 megahertz at the end of the 20th century. Recent designs are edging toward 10 gigahertz.

Memory

The other crucial function of a computer is *memory:* the ability to store numbers or other data, and usually the instructions that make up a program, within its circuits. Each *word* of memory is stored in multiple binary circuits. Every word has its own numerical *address,* which the CPU can use to find it. In the standard design, *random access memory (RAM),* every address can be accessed in the same amount of time, typically one clock cycle. A task larger than a computer's RAM can hold requires some form of *storage* (below), which slows its operations.

Storage and Media

In addition to RAM, a computer usually stores information in other media. The capacity of such storage can be much higher than that of its RAM. However, access is slower, and it takes extra time to move to different sections of the data. Computers have used a series of different media since the 1940s, as discussed in ***High-Tech,*** pp. 21-22.

Architectures

The concept of a *stored-program computer,* where the program and the data are kept in the same memory circuits, was described in 1945 and is called the *von Neumann architecture*. This has a single CPU that reads instructions and data from the RAM and stores results there. This one-step-at-a-time execution of programs is known as *serial computing*.

Higher speeds can be attained by *parallel computing,* in which two or more CPUs (often controlled by the same clock) carry out instructions at the same time. Ideally, all of them would be active all the time; in practice, most programs leave some CPUs idle some of the time, so the factor of speedup is less than the number of CPUs. Theoretical proposals for parallelism appeared in 1958, and the first parallel computers were built in 1962. A further extension of this concept is *distributed computing,* discussed under *Networks* (p. 41).

Massively parallel computing, with 100 or more CPUs, was developed in 1983 for processing of satellite imagery. Many supercomputers are massively parallel systems.

In 2001, a further extension of parallelism emerged: the use of graphics processing units (GPUs) for computing as well as graphics. In effect, a CPU outsources computational tasks to multiple GPUs. This was originally done to speed up graphics processing, but turned out to apply to many scientific computation problems. It has been used in some recent supercomputers. This architecture is one way to create a *fast* computer (see *Computer-Design Options,* p. 37).

Specifications

Computers in ***GURPS*** are classified by physical size. This is the size of the internal electronics, such as the CPU, any GPUs, the internal storage, and the power supply; it doesn't include added external storage or input/output devices. Standard size categories at TL8 are as follows (some have different names from those in ***High-Tech,*** based on historical terminology).

Megacomputer (TL7): An early, very large computer, or a computer complex at a major research facility. Industrial power. $10,000,000, 20 tons. 1940. Complexity 7.

Macroframe (TL7): A smaller early computer, a first- or second-generation mainframe, a large mainframe owned by a major organization, or a small supercomputer. Industrial power. $1,000,000, 2 tons. 1940. Complexity 6.

Minicomputer (TL7): A compact, less expensive computer, first built to take advantage of early integrated circuits – typically about the size of a refrigerator. Later models are called "midrange computers." Major appliance power. $100,000, 400 lbs. 1969. Complexity 5.

Workstation (TL7): A one-person computer, sometimes built into a workstation terminal (p. 40). Includes larger desktop computers such as the first IBM PC. Household power. $10,000, 40 lbs. 1973. Complexity 4.

Medium Computer (TL7): A smaller desktop (often built into a monitor or keyboard), or the internal components of a laptop. Household power or Rechargeable/8 hours. $1,000, 4 lbs. 1977. Complexity 3.

Small Computer (TL8): The internal components of a notebook, palmtop, or tablet. Rechargeable/8 hours. $100, 0.4 lb. 1996. Complexity 2.

Tiny Computer (TL8): The internal components of a smartphone or wearable. Rechargeable/8 hours. $50, 0.04 lb. 2007. Complexity 1.

Bigger computers have more RAM (and sometimes more CPUs) and run bigger, more complex programs. This gives rise to the above Complexity ratings. See *Computer Design Options* (below) for variations on those ratings.

Computers at TLs lower than 8 have lower Complexity and other special features.

The rules in ***High-Tech*** treat all TL8 computers as having the same Complexity. But Moore's Law (see *Miniaturization,* p. 6) didn't stop working in 1980! Different stages of the development of integrated circuits (see p. 6) provide different capabilities.

Finally, various design options can be applied to customize these computers; see *Computer-Design Options* (below). Such changes affect cost and weight, as well as other aspects of the computer. Multiply the listed cost and weight factors together if multiple options are taken.

Example: The original IBM personal computer, released in 1981, is a compact, slow early-VLSI workstation. It weighs 20 lbs. (40 lbs. × 0.5 × 1), costs $1,000 ($10,000 × 2 × 0.05), and has Complexity 2 (4 - 1 (Early VLSI) - 1 (Slow)).

Computer-Design Options

This table summarizes available options for computers. The year specifies when the option is first available. MSI is medium-scale integration; LSI is large-scale integration; VLSI is very-large-scale integration. See *Miniaturization,* p. 6, for more about integrated circuits. Dedicated hardware has its programs built into it. For expanded descriptions of other options, see ***High-Tech,*** pp. 20-21. (For a variant design system with different alternative assumptions, including fractional tech levels, see "Thinking Machines," from *Pyramid #3/37: Tech and Toys II.*)

TL	*Option*	*Year*	*Weight*	*Cost*	*Complexity*	*Notes*
Basic Technology						
7	Electromechanical	1940	–	–	-5	Hardened at no extra cost.
7	Vacuum tube	1939	–	–	-4	Hardened at no extra cost. Roll daily vs. HT for tube burnout (requires minor repairs, p. B484).
7	Transistor	1947	–	–	-4	Compact (see below) at no extra cost.
7	MSI	1968	–	–	-3	
7	LSI	1971	–	–	-2	
8	Early VLSI	1980	–	–	-1	
8	Standard VLSI	1990	–	–	0	
8	Late VLSI	2000	–	–	+1	
8	Advanced VLSI	2010	–	–	+2	
Customized Hardware						
7	Compact	–	×0.5	×2	–	See also *Miniaturization,* p. 6.
7	Dedicated*	–	×0.2	×0.5	–	Programs cannot be changed.
7	Hardened	–	×2	×2	–	+3 HT vs. electromagnetic pulse.
7	High-capacity	–	–	×1.5	–	Runs 50% more programs; see *Processing Power,* p. 36.
8	Fast	–	–	×20	+1	May not be combined with Slow.
8	Slow	–	–	×0.05	-1	May not be combined with Fast.

* See *Hard-Wired Programs* (p. 38) for further game mechanics and *Special-Purpose Devices* (p. 39) for examples.

From High-Tech to Ultra-Tech

Under the alternative rules for the Complexity of TL8 computers, an advanced-VLSI computer is the equivalent of a TL9 computer in ***GURPS Ultra-Tech.*** Ultra-tech computers might well be even more advanced. What can such a computer do?

One way to approach this is to assess the complexity of tasks such as scientific modeling more realistically. For example, in 2007, a Swiss research institute used an IBM Blue Gene/L supercomputer to simulate *one* cortical column of a rat brain at the molecular level. This was a fast advanced-VLSI macroframe (see *Processing Power,* pp. 36-37), giving it Complexity 9. A human brain has one million cortical columns, each about six times as complex as a rat's; the Complexity of a molecular-level human-brain simulation would be at least 16!

Whether computers continue to progress after TL8 is uncertain. It's commonly believed that Moore's Law (see *Miniaturization,* p. 6) is reaching its limits; advanced VLSI might be the best possible. Proposed new methods, such as three-dimensional integrated circuits, use of carbon nanotubes instead of silicon, or a change from electronics to photonics, might enable further improvement. Or a superscience form of computation might be discovered and change everything.

Programs and Languages

A computer's circuits can carry out many different algorithms. Implementing algorithms uses the skill of Computer Programming, which creates *programs.* But once a program is designed, it has to get into the computer.

Hard-Wired Programs

Very early computers, at the end of TL6 and the first years of TL7, were designed to carry out specific tasks; for example, the Atanasoff-Berry computer (conceived in 1937, prototype built in 1942) solved systems of algebraic equations with up to 29 variables. In ***GURPS*** terms, such a device is a dedicated computer (see *Computer-Design Options,* p. 37). "Programming" means designing its circuits, and uses Engineer (Electronics) skill, at -2 if the designer isn't familiar with digital circuits; there isn't a separate Computer Programming skill. If a program has been designed for a particular class of machines, a specific machine can be rewired to carry it out with a roll against Electronics Repair (Computers).

Very early TL7 machines, such as the Colossus cryptographic computers at Bletchley Park, had jacks or switches set up to change their configurations. Making such changes uses the skill Computer Operation. ENIAC, the first general-purpose computer (which came into use in 1946), had a staff of half a dozen women "operators" who developed configurations for it, in effect teaching themselves Computer Programming on the job.

Machine Language

The next step was storing programs in a computer's memory. Proposed in 1945, this approach was implemented in 1948 in a small experimental computer at the University of Manchester, nicknamed "Baby." The UNIVAC I, brought on the market in 1951, used this approach.

Early programs were written in *machine language,* as words in the computer's memory. Writing machine code, or finding problems in it, is a slow, tedious process; apply -5 to Computer Programming, which can be bought off by taking extra time to consult reference books (*Time Spent,* p. B346), or avoided with the aid of Eidetic Memory (as in Robert Heinlein's novel *Starman Jones*).

Symbolic Languages

By the late 1940s, programmers figured out a way around this problem: having *the computer itself* look up the machine code. The programmer wrote easily remembered abbreviations for things the computer could do, and relied on the computer to translate them into instructions it could understand. These abbreviations made up *assembly languages.* Their use eliminates the penalty to Computer Programming for using machine code. However, working with a new assembly language imposes penalties for unfamiliarity.

During the 1950s, programmers developed *high-level languages,* such as FORTRAN (1954) and COBOL (1959). Rather than each instruction representing one step of the program, an instruction might represent a whole series of steps. Different computers could translate programs into their own machine languages, allowing the same program to run on computers of different models. This led to the idea of *software* as an independent system, separate from the *hardware* of the machines that ran it – and avoided unfamiliarity penalties for programming new machines. However, a clever programmer may exploit particular features of a specific machine, using Computer Operation – which *is* subject to familiarity penalties! – as a complementary skill to Computer Programming, granting +1 on success, +2 on critical success, -1 on failure, and -2 on critical failure.

Artificial Intelligence

GURPS uses "AI" for a meta-trait that represents self-aware robots. This isn't what "artificial intelligence" means in computer science. Primarily, it means that the system can develop new capabilities in some area; for example, a mail program can learn to predict which messages its user will reject as junk mail, and move them to a junk folder.

Artificial intelligence is a step beyond programming, enabling a computer to come up with new solutions to problems, sometimes problems its programmers didn't know how to solve. Early work, starting in 1956, focused on *symbolic AI,* which manipulated digital strings according to formal logical rules (later nicknamed GOFAI, "good old-fashioned artificial intelligence"); researchers were confident that this would lead to human equivalence. By the 1980s, AI had stalled in areas such as vision, natural language processing, and pattern recognition. A second wave of research turned to *neural networks,* which generalize from examples in a manner somewhat similar to human brains (starting in 1986, with the aid of much greater computer power), and *embodied intelligence*, which emphasizes the control of robotic bodies (starting in 1980; see *Automatic Control and Robotics,* p. 25). Over the course of TL8, AI has been incorporated increasingly into computer software.

Special-Purpose Devices

Digital circuits have also been used in a variety of single-purpose devices. In general, these amount to dedicated computers (see *Computer-Design Options,* p. 37). With continuing advances in miniaturization, some devices have expanded their range of functions, often to the point of serving as general-purpose computers, such as the "smartphone"; others, such as the electronic typewriter (p. 23), have been abandoned, with their functions incorporated into multipurpose devices. Chapters 2, 4, and 6 list other special-purpose devices. Simple devices can be used without a skill roll; using more complex ones is included in the skill they help with – for example, Accounting or various branches of Mathematics for calculators.

Desktop Calculator (TL7). A large machine that electronically adds, subtracts, multiplies, and divides. An early relay-based model (1957) was actually as large as a whole desk and weighed 300 lbs. It was quickly replaced with tube-based electronic devices. Household power. $750, 40 lbs. 1961. Transistorized models were smaller but costlier: $1,500, 20 lbs. 1973.

Electronic Watch (TL7). Early watches used a variety of circuits and mechanical components. The quartz watch, based on an oscillator controlled by a quartz crystal, became standard because of superior durability and accuracy. T/1 year. $25, 0.25 lb. [1957] 1969.

Pocket Calculator (TL7). A pocket-sized device that adds, subtracts, multiplies, and divides; more advanced models carry out scientific, statistical, or financial calculations (treat as good equipment). T/1 day. $40, neg. [1967] 1971.

Digital Watch (TL7). LCD and LED displays led to the emergence of the *digital watch,* with a numerical display rather than hands. T/1 year or solar powered. $20, 0.25 lb. [1970] 1975.

Game Console (TL7). The first game played on a video display was patented in 1947, and the use of computers to play games began in the 1950s. Large arcade games came on the market in the 1970s, followed shortly by home game consoles used with a separate video monitor or television (p. 34). Runs games stored on ROM cartridges ($35; 0.2 lb.). Household power. $120, 3.5 lbs. [1951] 1976.

Programmable Calculator (TL8). A calculator that can carry out and store a short program defined by the user (roll vs. Computer Programming). T/1 month or solar powered. $40, 0.75 lb. [1974] 1979.

Pocket Calculator (TL8). Uses inexpensive integrated circuits and has much lower power consumption. T/1 month or solar powered. $6, neg.

Game Console (TL8). A handheld console, two or more of which can be linked together for multiplayer games. 4×XS/30 hours. $25, neg. 1989.

GPS (TL8). A handheld device that receives radio signals from global navigation satellites and uses them to identify its own position and the exact time. Gives +3 to Navigation (Air, Land, or Sea) if a satellite constellation is above the horizon. 2×S/40 hours or automotive power. GPS is increasingly incorporated into smartphones and other portable computers, and into vehicles. $75, 0.25. [1978] 1989.

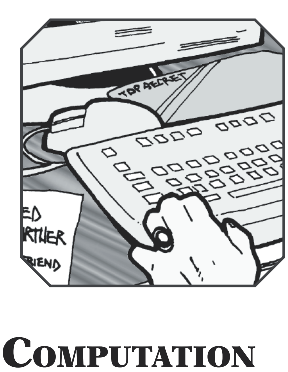
E-Reader (TL8). A handheld device that stores the texts of a large number of books and displays them on an LCD or LED screen. Peripheral power or T/15 hours. $90, 0.5 lb. [1998] 2006. This function is now routinely incorporated into tablets (see *Small Computer,* p. 37).

Digital Interfaces

The first generation of computers relied on *batch processing,* in which large jobs were queued up to be fed through the computer. Once the *stored-program computer* (p. 36) was developed in 1949, programs were entered in the same way. These devices had only a few real-time controls and weren't suited as interfaces for human control of other machines.

Interactive processing permitted an operator to select operational modes and input programs and data in an ongoing process, allowing more flexible scheduling. A variety of methods have been used. Each can be considered a different familiarity within Computer Operation, with unfamiliarity penalties when it's first encountered: -2 to effective skill for the first 8 hours.

A computer's Complexity limits what type of interface it can work with, and what type of material it can display. The computer's clock speed (p. 36) must be high enough to meet the bandwidth requirement (*Bandwidth,* p. 28).



Complexity 1: Text interface, often via keyboard.
Complexity 2: Graphic interface, usually with a pointer device.
Complexity 3: Music and video output.
Complexity 4: Controlled by spoken commands or gestures.
Complexity 6: Controlled by brain-computer interface.

Physical Controls

Ongoing interaction between computers and human operators began in 1963 with the use of a teletype keyboard as an input device and a teleprinter as an output device (*Teletype,* p. 26). By 1969, the cathode-ray tube came into use as a "glass TTY," giving rise to the *terminal* (though teletype interfaces remained in use through the mid-1980s). The year 1971 saw the creation of UNIX, the first modern command-line interface (CLI); a year later, a version written in the high-level language C was usable on a wide variety of machines. *Disk operating systems* for machines that used magnetic disks for storage became available in 1966. These systems were adapted to personal computers (in ***GURPS*** terms, medium computers; p. 37) in 1980 with MS-DOS (TL8).

The graphic user interface (GUI) was developed in 1963 for special-purpose applications such as computer-aided design (CAD) and began to be applied to general-purpose computers in 1973. It was fully commercialized in 1984 with the release of the first Macintosh (TL8). GUIs required a *pointing device* to select text or graphical objects (icons) on a monitor screen. Some such devices were originally developed for other purposes and later adapted to work with computers.

Joystick (TL7). The electric joystick was originally developed to control aircraft remotely (*Remote Control,* p. 25) and was used for this during World War II; it was later adapted to video games. $25, 3 lbs. [1926] 1969.

Light Pen (TL7). Invented early in the development of mainframes, for use with CRT displays, primarily of graphic output. Came into more general use with standard terminals based on a keyboard and monitor. However, it has to be held up to the screen, causing fatigue and even repetitive stress injury to the arm; roll vs. HT every 10 minutes, with failure costing 1 FP and critical failure also costing 1 HP. Because of this, other pointing devices became more popular. $35, neg. [1955] 1969.

Workstation Terminal (TL7). A teletype system can be used as an improvised terminal; roll vs. Electronics Repair (Computers) to set up. Allows Computer Operation rolls at no penalty, but takes 4× as long for most tasks. A standard terminal has a keyboard and monitor. A printer (pp. 23, 33) has to be added separately, but multiple terminals or computers may share a printer. Household power. $375, 25 lbs. [1963] 1969. At TL8, halve weight.

Joystick (TL8). A digital version using peripheral power. $25, 3 lbs. 1977.

Keyboard (TL8). The equivalent of a teletype keyboard, often with extra keys for numerical input or to control computer functions or navigate the screen of a monitor. Sold separately for use with desktop computers. Navigating a video display with only the up, down, left, and right arrows of a keyboard (common in CLI systems) gives -1 to effective skill; this can be compensated for by taking extra time. Peripheral power. $75, 0.5 lb. 1981.

Mouse (TL8). The most commonly used pointer for GUIs on desktop computers. Peripheral power. $10, 0.25 lb. [1964] 1984.

Portable Terminal (TL8). A flat screen, a keyboard, and usually a trackpad built into the case for a laptop. Power comes from the computer contained in the case. The configuration is slightly awkward and gives -1 to skill for long or graphics-intensive tasks. $50, 0.5 lb. 1986.

Trackpad (TL8). An alternative pointer for a desktop computer, and built into laptop computers. T/2 weeks or peripheral power. $95, 0.5 lb. [1982] 1994.

Wireless Mouse (TL8). Uses internal batteries recharged by peripheral power, and tracks position optically rather than mechanically. $10, 0.25 lb. 2000.

Wireless Keyboard (TL8). Uses internal batteries recharged by peripheral power. $75, 0.5 lb. 2005.

Touch Screens

Touch screens allow finger touches and motions on a video display to provide input to a computer. They were invented in 1965, but the first commercial applications dated to the 1980s, including controlling an automobile's auxiliary systems (1985) as well as computer input. Early versions had trouble determining exact finger position, giving -2 to effective skill. After 1988, it became possible for touch-screen users to select a single pixel. Prototype multitouch systems (able to respond to two or more fingers) were created in 1984, and multitouch became commercially available in 2005.

Touch screens were used in palmtop computers starting in 1992, in smartphones in 1994, and in tablets in 2010. Since 2000, touch screens have come into use as control interfaces for devices such as printers and for remote-control systems.

Stylus (TL8). A penlike device that allows more precise control of a touch screen; +1 quality modifier to effective skill. Does not provide a multitouch option. $6, neg. [1965] 1988.

Touch Screen (TL8). A computer interface based mainly on a touch screen. Gives -1 to tasks that involve typing, but can be used with a separate keyboard. [1965] 1988. Comes in three main sizes:

Desktop: Comparable to the screen of a laptop, but can be freestanding. Multitouch versions (since 2005) give +1 to Computer Operation. Household power. $175, 3 lbs.

Tablet: A screen with a 10" or less diagonal. Early single-touch versions give -1 to Computer Operation. Powered by the computer contained in the case. $80, 0.5 lb.

Phone: A screen suited to a smartphone. Multitouch versions give -1 to Computer Operation; single-touch versions give -2. Powered by the smartphone contained in the case. $35, neg.

Voice-Controlled Systems

An important application of AI has been understanding human speech. Early experiments, starting in 1952, could take hours to process seconds of speech. Real-time systems appeared in 1987 (TL8), taking advantage of neural-network programming (see *Artificial Intelligence,* p. 38). Systems capable both of turning speech into text and of recognizing and responding to spoken commands have been available since 2010.

Voice control allows hands-free operation, which benefits users whose hands are occupied or nonfunctional. It's also beneficial for users with dyslexia, reducing the risk of spelling errors. Voice control became a symbol of high technology in many science-fiction dramas and technothrillers. However, for navigating a screen, it gives -2 to Computer Operation and other skills. An initial training period of 8 hours is needed for the system to become familiar with the user's voice; until then, rolls to operate devices by spoken commands are at -2.

Smartphones, tablets, and standalone devices may send spoken questions or commands to a remote computer capable of interpreting speech (*Digitally Encoded Voice and Video,* p. 41), if they have network access. This creates a possibility of gaining access to other people's conversations with a Computer Hacking roll (or its realistic equivalents; see p. B184) – or a court order!

Smart Speaker (TL8). A purely or primarily acoustic interface for accessing a remote computer, containing small loudspeakers and multiple microphones (to detect a user's location). Typical models can play music, access a network, answer questions, and sometimes control other devices. Household power. $75, 2 lbs. [2010] 2015.

Virtual Reality

The first experiments with virtual reality took place in 1968, but it was several decades before commercial release of headsets. Many early systems were used in electronic games to give a more immersive experience, but more practical uses followed. Virtual-reality-display systems allow computers to be used for three-dimensional design; they can also be integrated into remote-control systems (p. 25). The main current limitation of virtual reality is its ability to deal with motion, force, and the sense of touch. Current systems using prototype devices such as *wired gloves* give -2 to skills based on manual dexterity.

Virtual Reality Headset (TL8). A headset that provides separate video images to both eyes, allowing three-dimensional imagery, together with stereo sound. Also provided is a handheld pointer device for selecting and moving virtual objects. If used for Computer Operation, it offsets up to -2 in penalties for tasks that would benefit from wearing a VR headset. Peripheral power or XS/15 hours. $85, 6.5 lbs. [2010] 2016.

Brain-Computer Interfaces

Experiments with direct control of computers and other devices by the brain began in 1969. In 2015, the BCI Society began holding annual international conferences. Such devices are prototypes at present. Two basic approaches are *invasive,* using surgically implanted electrodes, and *noninvasive,* based on electroencephalography, magnetic resonance imaging (MRI), or other methods of scanning brain activity. Noninvasive interfaces based on wireless EEG headsets (p. 12) produce weaker signals, for -2 to skill rolls (which can be compensated for by taking extra time). Applications include control of computers and of wheelchairs and prosthetic limbs. Average complexity.

Networks

Linking computers together to exchange data, and to let one computer control another, began around 1960. In 1969, four research centers were linked to form ARPANET, which evolved into the Internet. This became a key technology of TL8 after commercialization of Internet access in 1989. Rates of data transmission increased steadily, with the Internet developing into a new utility and then into a common amenity.

Networking allows new approaches to computer use. *Cloud computing* stores data and sometimes programs on a network, as backup for a local system or as an alternative to it, reducing local storage requirements – but if locally stored copies aren't available, being cut off from its network makes a computer much less useful. *Distributed computing* extends parallel computing (see *Architectures,* p. 36) to have computers on a network carry out different parts of a task. This can boost a computer's effective Complexity. Some users donate unused processing time on their systems; others engage in computer hacking to steal processing time, or write programs that do this automatically.

Local Networks

Computers at single sites can be linked together by wire or wirelessly. Ethernet became the dominant wired technology in the 1970s, with rates increasing from 2.94 megabits/second to 400 gigabits/second. Wireless networks emerged over the 1990s; the name "Wi-Fi" came into commercial use in 1999.

Ethernet Adapter (TL8). A device that can be connected to a computer's bus, or in later versions to a USB port. It enables Ethernet communication via coaxial cable ([1973] 1982), copper twisted pair connectors ([1983] 1986), or fiber-optic cable ([1978] 1993). After 1990, Ethernet capability was built into most computers. $10, neg.

Router (TL8). A device that connects with multiple computers and other devices within a house or office, letting them exchange files and assign each other tasks. Routers are usually connected to a modem via Ethernet, providing Internet access. Household power. $150, 1.5 lbs. 1997.

Long-Range Networks

The standard way to connect a computer to the Internet is with a *modem* (short for *modulator-demodulator*). Modems actually came before the Internet; for example, they connected air defense sites in North America starting in 1958. General use began after 1968, when the FCC authorized the use of third-party devices sending audio signals over telephone lines.

Modem (TL7). A device that translates digital data into an analog signal for transmission to a remote location. Early modems sent audio signals, originally at 300 bits/second, and had to be manually controlled. Household power. $50, 1.25 lb. 1969.

Modem (TL8). A device directly controlled by a computer and capable of higher speeds, starting at 1,200 bits/second, letting it be used for file transfer. Household power. $50, 1.25 lb. 1981.

Broadband modem (TL8). Digital signals allow transmission rates in megabits/second over phone lines or television cable. Treat as cutting edge (p. 8) until 2004. $50, 1.25 lb. 1988.

Digitally Encoded Voice and Video

Digital encoding of the human voice goes back to the 1930s, as a means of saving bandwidth on telephone lines, and was used for secure communication during World War II. More advanced versions were built into mobile phones starting in 1991. *Voice over Internet protocol* (VOIP) allowed the use of a computer with audio input and output for voice communication via a broadband connection.

Digital videotelephony became technically possible in the 1980s, but initially required a workstation computer (p. 37) with specialized components, costing over $200,000. With the emergence of broadband, videoconferencing via the Internet became possible, with a small video camera/microphone plugged into a computer (or built in, in more recent models).

Chapter Six
Electronic Warfare

Electrical and electronic devices have a variety of "adventuring" applications, from combat to crime. These are based on technologies described in the preceding four chapters, but it's convenient to have all these applications in one place. Adventuring gear has HT 12.

For a discussion of terms used in equipment descriptions, see *Understanding the Devices,* pp. 8-9.

Security and Espionage

Electronics plays a role in maintaining the security of fixed installations, at every level from home protection to top-secret military facilities – or violating it! The following devices will be of interest to burglars, spies, and assassins, and to the guards who have to stop them. Use Electronics Operation or Electronics Repair (Security) if a skill roll is needed, unless otherwise specified.

Electric Fences

Electric fences are primarily used for livestock control and to keep wild animals off human property. However, higher-powered fences for military use came first (1915 vs. 1936). See ***High-Tech,*** p. 204, for the TL6 versions. Also see *Security Fence* (p. 44).

Low-Voltage Fence (TL7). Used for animal control or for home or private business security. Causes nonlethal electrical damage (p. 9) resisted with an unmodified HT roll each second, as well as Moderate Pain (p. B428). Stun lasts while contact is maintained, and a HT roll is required to recover after it's broken; this may be attempted once per second. Can be extended to up to 20 miles. Per mile: XL/5 weeks, automotive power, or household power. $800, 1,200 lbs. 1962.

High-Voltage Fence (TL8). "Stun-lethal" fences deliver low-voltage effects at a first touch, and high-voltage ones at a second. High voltage inflicts 3d burning damage per second as lethal electrical damage (p. 9). Statistics for 0.25 mile of fence: Industrial power. $10,000, 500 lbs.

Locks and Lockpicks

In dealing with conventional mechanical devices, a *digital stethoscope* (p. 14) provides bonuses: +1 to safecracking rolls, +3 to rolls to defeat security devices if hearing the mechanism would help, +1 to Explosives (EOD) rolls to detect or defuse mechanical bombs, and canceling -1 in penalties to these tasks from noisy environments.

Electrical locks and their control mechanisms, and devices for countering them come into use in the 20th century. Electrical locks are either *fail-safe* (shutting off the power opens the lock) or *fail-secure* (shutting off the power closes the lock). They can be turned on or off by a simple switch on one side of the door or by a variety of control mechanisms, including devices listed under *Screening* (p. 43).

Key Switch (TL6). An electric switch operated by a key, turning on power to open an electric deadbolt or activate other devices (in particular, automobiles). Roll vs. Electronics Repair (Security) or Mechanic (vehicle type) to bypass, or make a standard Lockpicking roll (p. B206). $10, 0.5 lb. 1913.

Electric Deadbolt (TL6). A deadbolt that's either closed (fail-safe) or opened (fail-secure) by an electromagnet. Automotive or household power. $30, 2.5 lbs. 1914.

Keypad Combination Lock (TL6). A numeric keypad that opens a lock when a specific sequence of digits (usually from four to six) is pressed. Household power. $160, 1.5 lb. 1926.

Electronic Lockpicking Kit (TL7). Specialized mechanical and electronic tools for accessing and subverting a security system's circuits. Basic equipment for Electronics Operation (Security). 3×S/week. $1,500, 3 lbs. 1940.

Magnetic Lock (TL7). Holds a door closed with a powerful magnetic field generated by an electromagnet (pp. 22-23) mounted on the doorframe. An intruder can shut off the power with an Electrician roll. Household power. 1969. Available in several standard sizes with different effective strengths (figured as for electromagnets, pp. 22-23):

Micro: 275 lbs. force (ST 12). $60, 3 lbs.
Mini: 650 lbs. force (ST 18). $65, 6 lbs.
Midi: 800 lbs. force (ST 20). $70, 8 lbs.
Standard: 1,200 lbs. force (ST 24). $75, 12 lbs.
Shear: 2,000 lbs. force (ST 32). $80, 20 lbs.

Smart Lock (TL8). An electric deadbolt designed for wireless control by a coded signal from a specialized key fob or a smartphone. 4×XS/20,000 uses. $110, 0.9 lb. 1989.

Screening

Screening devices provide ways to verify identity. They can be used by a human guard, connected to an electronically controlled lock, or, recently, controlled by a suitably programmed computer.

Keycard Reader (TL7)

A device that can read an access code number from a wallet-sized plastic card. XS/1 year. $35, 0.5 lb. Multiply cost ×2 if the device keeps a record of scanned cards. Several technologies have been used:

Optical Barcode: A pattern of wide and narrow stripes that can be visually scanned. [1949] 1974.

Magnetic Stripe: A strip of magnetic material on which data can be recorded. [1971] 1975.

Holepunched: A pattern of holes, which can be read by photoelectric sensors. 1980.

RFID: A conductive loop that harvests power from a small radio transmitter to send a return signal; physical contact isn't necessary. The same technology is used to track property and prevent theft, and for other purposes – even implanted subcutaneously in animals to identify strayed pets. Multiply reader cost ×2. [1973] 1983.

Smart Card: A microchip with stored identifying data, powered through electrical contacts on the surface. [1968] 1983.

Biometric Identification (TL8)

Devices that recognize some distinctive trait of the person being identified. Normally used in a fixed location with household power; however, security personnel may carry models with rechargeable batteries (recharged daily; add 0.2 lb. to weight and $5 to cost). A basic system (as specified below) can be bypassed by opening its case and modifying its circuits with a roll vs. Electronics Repair (Security) at +5; a good system (×5 cost) requires an unmodified roll, and a fine system (×20 cost) requires a roll at -5. Any such device can keep a record of persons identified at no added cost.

Signature: An intruder with Electronics Operation (Security) skill can attempt a Forgery roll at -3. $200, 2 lbs. 1977.

Voiceprint: Requires a good microphone. A high-quality recording of a password spoken by an authorized entrant can bypass the system. $100, 0.5 lb. 1983.

Hand Geometry: Performs a large number of anthropometric measurements on a human hand. $120, 4 lbs. 1985.

Fingerprints: A *basic* device can be fooled by breathing on the scanner, which causes it to read the last print scanned. High-quality visual imaging equipment can produce a counterfeit fingerprint. $40, neg. 1986.

Retinal Patterns: Scans a person's retinal blood vessels. In cinematic campaigns, it might be fooled by surgery or special contact lenses. $500, 2 lbs. 1994.

Facial Recognition: Uses the shape of the face; now being adapted for use on computers (including smartphones) with camera input, without a separate scanner. 2006. $75, 1 lb.

Portable X-Ray Machine (TL8)

An X-ray source and receiver that can be placed on either side of an object to be scanned, connected by a cable or wirelessly to a laptop control unit with a video screen, allowing examination of internal contents or components. Gives +4 to Explosives (EOD) to defuse a bomb or +5 to Search to examine a package's contents. Rechargeable/3 hours. $50,000, 25 lbs. 1987.

Security Metal Detector (TL8)

A handheld device that can be scanned up and down a person to detect concealed metallic objects. Gives +1 to Explosives (EOD), Search, or Traps rolls; if it's combined with a 1-minute pat-down, the Search roll is at +2. Roll vs. Electronics Operation (Security) for improvised use of general-purpose metal detectors. S/10 hours. $250, 1 lb. [1972] 1995.

Alarms

Alarm systems connect a sensor to a signal, such as a bell, buzzer, or flashing light. This signal may be close to the sensor (to make the intruder retreat) or in a more distant location such as a building security office or police station (to capture the intruder). In high-security locations, it may activate countermeasures, from locking doors to firing weapons. Up through TL7, wires connect the devices; at TL8, wireless systems become increasingly common.

Spotting an alarm requires a roll vs. Vision-5, Observation, or Per-Based Traps, or a Quick Contest vs. Camouflage if the device is hidden. Identifying the type requires a roll vs. Electronics Operation (Security). Disabling an alarm requires a roll vs. Electronics Repair (Security). An unsophisticated system can be shut down with an Electrician roll to shut off power (if it doesn't have its own batteries) – but doing this to a professionally designed system sets off alarms!

Electric Alarm (TL5). An electric circuit that crosses a door or window; if this is opened (or a window is broken), current stops flowing and the alarm goes off. Simple enough to be disabled with a roll vs. Traps. Per portal: M/1 month or household power. $200, neg. [1853] 1857.

Pressure Mat (TL6). A flat device that signals when stepped on. Can provide security for an entry or passageway, show when a patient gets out of bed, or open doors automatically. Per square foot: $50, 1 lb. 1930.

Ultrasonic Alarm (TL7). A motion-detector system that fills a room with ultrasonic waves and responds to changes in the frequency of reflected waves when someone moves through. Can be used to turn on lights when someone enters a room. Household power. $100, 1 lb. [1945] 1953.

Proximity Sensor (TL7). A circuit that responds to the body capacitance of anyone who comes closer than 1 yard. Household power. $40, neg. 1958.

Car Alarm (TL7). A motion sensor for an automobile, based on mercury switches that conduct electric current if the vehicle is tilted or suffers an impact, setting off a loud noise. At TL8, often built into the vehicle and recharged by automotive power. 2×XS/6 months. $240, 2 lbs. 1970.

Photoelectric Beam (TL7). Based on photodetectors (p. 12), this alarm system has beams of visible or near infrared light crossing a doorway, corridor, or other space; interrupting a beam sets off an alarm. Beams can be up to 3 yards long. Household power. Per beam: $15, 0.5 lb. 1972.

Security Fence (TL7). Carries an imperceptible current flow that sets off an alarm when someone comes in contact with it. Add $100 to the cost of the fence. In a stun-lethal electric fence, this feature is free.

Infrared Motion Detector (TL8). Despite its name, this device doesn't detect motion as such, but rapid changes in temperature, as when a human being walks through a room. Operating range is 25 yards. Prototype models were likely to give false alarms; more sophisticated designs minimized this problem. Can be used to turn on lights when someone enters a room or outdoor area. Household power. $100, 1 lb. [1970] 1979.

Infrasonic Alarm (TL8). A microphone designed to pick up subsonic sound waves, such as those emitted by attempts at forced entry or by explosions. When a suspicious pattern is identified, the alarm is triggered. It doesn't respond to human or animal movements. Household power. $32, 0.5 lb. 2016.

Bugs and Taps

A major goal of covert operations is to find out what a rival or adversary knows, is thinking about, or is planning. Such information can be gained by spying on their communications channels and records. Electronic bugs and taps provide ways of doing this. Roll vs. Electronics Operation (Surveillance) to use this equipment, and vs. Smuggling to hide bugs.

At TL7, a device can be connected to an audiovisual transmitter. At TL8, a smart device can be programmed to respond to specific events.

Bug Detector (TL7). A small device sensitive to radio-frequency emissions over a broad range of frequencies. Roll vs. Electronics Operation (Security) to detect any bug or tap that includes a transmitter, at -5 if it uses spread-spectrum technology (pp. 46-47). Sweeping a room takes 1 minute per 100 square feet. Devices that record information rather than transmitting it can't be discovered in this way. Good- or fine-quality gear is briefcase-sized. 2×S/week. $500, 1 lb. 1940.

White Noise Generator (TL7). Generates random sound ("white noise") as a mask for conversation, hindering eavesdropping and audio bugs (***High-Tech,*** p. 208) and contact microphones, laser microphones and resonant cavity microphones (all below): -4 to the relevant rolls. It helps concentration on tasks; treat workers or students in the affected area as Attentive (p. B163) while exposed to it – but some people are sensitive to white noise as a quirk and experience Moderate Pain (p. B428). An FM receiver tuned to an unused frequency can serve as an improvised generator, but may pick up nonrandom signals, making it ineffective; roll vs. Electronics Operation (Media)-2 to avoid this. At TL8, digital systems become available with half the weight, and computers can be programmed to generate white noise digitally. 3×S/4 hours. $150, 4 lbs. 1940.

Resonant Cavity Microphone (TL7). Created in the Soviet Union to bug the U.S. embassy. Nicknamed "the Thing" when discovered. Hidden inside a large Great Seal of the United States was a 9" antenna (SM -5) connected to a very small condenser microphone. A beam of microwaves supplied power to the device, which modulated and retransmitted the signal. The device is considered a precursor of RFID (p. 43). Average complexity. [1945].

Isolator (TL7). Safeguards a bug against detection by a nonlinear junction detector (below). Radio-frequency emissions are diverted into a resistor that dissipates most of their energy. Gives -2 to rolls to detect a bug; SM -10. $400, 0.25 lb. 1956.

Contact Microphone (TL7). An extremely small microphone (SM -11) with adhesive backing, to be pressed against a flat surface. The operator can pick up sounds from the other side, at a penalty equal to the barrier's (DR + HP)/5, rounded down. T/week. $40, neg.

> *What physical science can devise and synthesize, physical science can analyze and duplicate.*
>
> *– E.E. Smith,* ***First Lensman***

Lock-In Amplifier (TL7). See p. 11 for statistics. If a signal generator (p. 11) is used to introduce a known signal into a facility or communications channel, a lock-in amplifier can isolate even faint traces of that signal externally, allowing identification of actual or potential leaks. Searching takes 1 minute per 100 square feet; roll vs. Electronics Operation (Security)+6 (+10 for a digital lock-in amplifier).

Laser Microphone (TL7). Shines a laser beam onto a reflective surface. When sound waves make the surface vibrate, changes in reflected light frequency are detected. If the internal sound waves are partially blocked by heavy curtains or triple glazing, roll at -2 to skill; noise such as running water gives -1 to -4. Laser microphones are immune to bug detectors. Range is 300 yards (900 yards at TL8). Household power. $5,000, 2 lbs. 1965.

Nonlinear Junction Detector (TL7). Sends out high-frequency radio waves that cause oscillations in solid-state devices. A sweep of a room detects any such device with an Electronics Operation (Security) roll. Originally created in World War II to find corrosion in aircraft, it also responds to such things as rusty nails; on failure by 4 or more, or critical failure, the operator mistakes such an object for a bug. M/5 days. $14,000, 7.5 lbs. [1941] 1972.

Computer-Emissions Interception (TL8). Peripheral devices associated with computers (including keyboards, CRT monitors, and flat-screen monitors) generate radio-frequency emissions during operation. These are usually regarded as "noise," but starting in the 1980s, a long series of researchers have demonstrated that information can be captured from them using relatively inexpensive equipment, compromising security – for example, a small computer (p. 37) and radio peripheral (p. 30). To put such a system together, roll vs. Electronics Operation (EW); to gain information from it, roll again at -1 per 100 yards over 300 yards range.

Keylogger (TL8). An electronic device that captures the characters typed on a keyboard. Early versions had to be physically wired into electric typewriters (with half an hour access and a roll vs. Electronics Repair (Surveillance)). After the emergence of desktop computers, commercially made devices could be plugged into the main computer and have the keyboard cable plugged into them in a "man in the middle" configuration, usually for later retrieval, though such a device can also be equipped with a built-in transmitter with range 2 miles. $100, neg. [1970] 1983. Keystrokes can also be logged by placing a concealed microphone close to the keyboard and analyzing subtle differences in the sounds of different keys, or by placing an accelerometer (p. 13) *on* the desk and analyzing the vibrations caused by typing. Either form of analysis requires a sample of 1,000 typed characters – about 200 words (the time required to collect this depends on the Typing skill of the user; see p. B228). After 2000, a smartphone can be programmed to perform either task.

Booster Bag (TL8). A homemade tool for shoplifters – a shopping bag lined with conductive material such as aluminum foil. Prevents RFID chips (p. 43) from registering with exit screening devices. Roll vs. Scrounging to construct one. [1983].

RFID Capture (TL8). Prototype devices for capturing data off of RFID chips (p. 43) have been constructed from an RFID scanner, an antenna, and a small computer. Roll vs. Electronics Operation (Security) at -2 to use, with -1 per full yard of distance to the chip. [2007].

Shielded Wallet (TL8). A wallet designed to block radio signals and prevent RFID cards (p. 43) from being scanned or copied. $35, 0.5 lb. 2010.

I'm still not sure what half of it is, but there's also a cell antenna on the roof, and ***that's*** *plugged into what appears to be a custom GNU radio box . . .*

– Charles Stross, ***Halting State***

The Electronic Battlefield

Electronic devices have functions in the changeable environment of military combat. Military electronics are ruggedly built, with HT 12 (rather than 10) and DR 8 (rather than 4).

Surveillance and Countersurveillance

Surveillance technology can detect attempted intrusions or approaches. Roll vs. Observation for visual systems or Electronics Operation (Security) for systems with electronic readouts. If the adversaries are hiding, the guard must win a Quick Contest vs. their Stealth, Shadowing, or Camouflage skill. If adversaries are based in a known location, surveillance technology can be used to keep watch on their activity with a roll vs. Observation or Electronics Operation (Surveillance). Roll vs. Intelligence Analysis to *interpret* new data.

A variety of countersurveillance methods are possible. Passive methods simply cover up the intruder's presence or identity; they often use Camouflage skill and don't involve electronic devices. Active methods try to disrupt the functioning of surveillance gear, typically with a Quick Contest of Electronics Operation (EW) vs. the skill of the observer.

Chaff (TL7)

Strips of aluminum-coated paper cut to half the wavelength of a targeting radar signal, dumped out of an aircraft. Dumping chaff doesn't conceal the aircraft's *presence* – it makes it more visible – but gives -2 to targeting per package dumped. $5, 1 lb. 1943.

Seismic Ground Sensor (TL7)

A microphone on a spike that's driven into the ground. To detect subsonic ground vibrations, such as footsteps or vehicles, roll vs. Electronics Operation (Surveillance) with bonuses based on size and speed, and a penalty based on range (*Size and Speed/Range Table*, p. B550). XS/3 months. $80, 0.3 lb. 1964.

Surveillance Camera (TL7)

A video camera that captures low-resolution images of a location and transmits them to a remote observer by wire ("closed-circuit television"). Observation rolls are at -4. After 1963, VCRs could be included in an improvised security camera system. In 1968, pan//tilt/zoom (PTZ) cameras operated by remote control (p. 25) became available for an added $300; the ability to focus on a specific location reduces the penalty to -2, but an intruder who succeeds in a Vision roll will notice the camera. In 1993, devices for connecting a camera to a computer become available. Household power. $150, 2 lbs. [1942] 1968.

High-Definition Surveillance Camera (TL8)

Reduces the penalty to Observation rolls to -2 (or eliminates it for PTZ cameras for an extra $300). Household power or rechargeable/24 hours. $150, 1 lb. 2003.

Reconnaissance UAVs (TL8)

Unmanned aerial vehicles ("drones") were originally created for military purposes. Experimental models saw specialized use in World War II; their use for surveillance dates to 1959. UAVs gained acceptance as effective combat equipment after Israel used them against Syria in 1982.

At TL8, UAV control systems incorporate specialized computers that give them enhanced autonomy. Widespread civilian use began in 2015, as technological advances (including smaller computers and longer-lasting batteries) made UAVs more affordable. The following examples illustrate options available to adventurers.

RQ-16A T-Hawk: A "micro air vehicle" originally built by Honeywell for the U.S. Army for reconnaissance and bomb detection, but subsequently turned to civilian uses. The entire package is 14" in diameter and can be carried in a backpack, with another pack holding the 32-lb. remote-control system. The main body holds a vertol system powered by a gasoline engine. Two pods at the sides carry the onboard control system and a modular sensor (a video camera and passive IR sensor are standard). The onboard autopilot provides Piloting (Vertol)-10 and Dodge-8. The remote-control system uses a touch-screen interface (p. 40) and track pen for +2 to *the operator's* Piloting rolls, and communicates with the craft by spread-spectrum radio (-4 to detect; see below). Fuel tank/40 minutes. Two T-Hawks and one control unit are $750,000, 69 lbs. 2007.

Phantom 4 Pro: A quadcopter designed for civilian professional use in photography and video, but adaptable to more adventurous tasks. Dimensions are 12" long, 7" wide, and 4.5" high. It carries a high-definition camera that can film video or take bursts of still photographs. An onboard autopilot provides flight stabilization and obstacle avoidance using infrared cameras with an 8-yard range; treat it as having Piloting (Helicopter)-14 and Dodge-9 for avoiding obstacles. Its remote control system uses a touch-screen interface that gives +1 to *the operator's* Piloting rolls. Rechargeable/30 minutes. $1,500, 3 lbs. 2017.

Reconnaissance UAVs Table

Terms and notation are as defined in *Vehicle Statistics* (pp. B462-463).

TL	*Vehicle*	*ST/HP*	*Hnd/SR*	*HT*	*Move*	*LWt.*	*Load*	*SM*	*Occ.*	*DR*	*Range*	*Cost*	*Loc.*	*Stall*	*Notes*
8	Phantom 4 Pro	6	+2/3	10	5/22	0.0015	N/A	-3	N/A	4	11	$1,500	4H	0	[1, 2]
8	RQ-16A T-Hawk	11	+3/2	12	5/29	0.01	0.001	-2	N/A	8	19	$375K	2s	0	[1, 2]

Notes

[1] Controller has 4-mile range limit for the Phantom 4 Pro; 7-mile range limit for the RQ-16A T-Hawk.

[2] Ceiling is 1,640' for the Phantom 4 Pro (because of limitations of the control systems) and 10,500' for the T-Hawk.

Communications and Encryption

Military application of telegraphy began in 1855, during the Crimean War. British field units drove wagons carrying telegraphic apparatus, batteries, and miles of wire, managed by squads of six to eight soldiers; messages could be sent to advance bases a few miles away. Telegraphy remained vital to military operations as late as World War I.

Radiotelegraphy came into use at the start of the 20th century, originally for naval warfare, as radio apparatus was so large and heavy that only a warship could transport it. By World War I, radio apparatus was mounted in aircraft or carried in wagons. World War II saw the use of voice radio, often small enough to be toted by the operator. Since then, radio gear has grown steadily smaller.

Spread Spectrum (TL7)

Military radio operates in a noisy environment and is often intentionally jammed (pp. 49-50). Spread-spectrum radio reduces these problems by using a wider bandwidth; it also makes signals harder to intercept. The first version was based on *frequency hopping* (coordinated changes of frequency by transmitter and receiver). It gives -4 to rolls to detect a radio signal and +4 to Electronics Operation (EW) to avoid interference from selective jamming (see p. 49). Such systems have ×2 cost and unchanged weight.

A more advanced technology, *direct sequence,* was experimented with as early as 1958, but became widespread after 1990 with the availability of small computers. Instead of hopping from frequency to frequency, it occupies a wide range of frequencies at once, with much lower power on any one frequency, and reduces maximum detection range to 1.5× standard range. The spreading involves a code sequence, so the signal can't be understood by anyone who doesn't know that sequence; the decoding process filters out most interference, giving +4 to Electronics Operation (EW) to avoid interference from broadband jamming or from other signals in the same frequency range. Treat as cutting-edge (p. 8) EW.

Signals Intelligence

Signals intelligence is the detection and tracking of radio messages, using Electronics Operation (EW). The practice emerged during the Russo-Japanese War (1904-1905), contributing to Japanese victory. The process was systematized during World War I, largely by British military intelligence. Most aspects of signals intelligence require specialized equipment (*SIGINT Gear,* p. 48); a standard radio receiver counts as improvised gear.

Monitoring routine traffic (cell phones, walkie-talkies, etc.) can be done with an ordinary receiver that operates on the correct band. Roll against Electronics Operation (Comm or EW) to see if the operator hears any conversation that might be of interest.

Detecting radio messages from a specific sender requires a radio tuned to the correct frequency. Different rolls are called for in three different cases. For *continuous transmission,* the signal is detected automatically, unless negative modifiers apply; in that case, roll after 1 minute. For *ongoing transmission* (such as exchange of messages during combat), the same rules apply, but a skill roll is always required. For *rare transmission,* roll for signal detection once per 4-hour watch; the GM decides whether there's any signal to detect. Apply all modifiers for tuning rolls, as discussed under *Tuning In* (p. 29).

If the frequency isn't known, monitoring *multiple channels* either requires one operator and radio per channel, or needs operators to divide their time between channels. For continuous or ongoing transmission, this takes as many minutes as there are channels. For rare transmission, divide the time into equal percentages, and round down to the next lower haste modifier (p. B346) – for example, -5 for two channels (50%) each, but -8 for four channels (25% each). A half-wave dipole or a loop of any size requires two searches per channel, because it needs to do two scans at right angles; a directional antenna requires *10* searches (see *Antennas,* p. 28). Intuition, p. B63, can reduce the number of channels or directions that need to be monitored.

To scan across a *frequency band* for continuous or ongoing transmission takes 15 minutes at TL6, 5 minutes at TL7, or 5 seconds at TL8 with computer-controlled scanning. A half-wave dipole or loop requires two scans, and a directional antenna requires 10. Scanning for rare transmissions still involves 4-hour watches, at -10 at TL6 (which doesn't mean the scan is completed instantly!) or -8 at TL7. Using a half-wave dipole or a loop gives an additional -4; using a directional antenna gives an additional -9.

Once a transmitter is detected, an antenna can be *aimed* at it – the same antenna, or a new one. Treat this as aiming an area attack (p. B413) for a dipole or loop, or as aiming a cone attack (p. B413) for a directional antenna, subject to the rules for scatter in either case (p. B414); if the transmitter was *originally* detected with a directional antenna, success is automatic. At TL6, or with improvised equipment, aiming an antenna takes 1 minute; keeping transmissions brief (less than 20 seconds for an encoded message) imposes haste penalties (p. B346). Any roll that places the transmitter within the antenna's area or cone allows its range multiplier to be applied, reducing or eliminating penalties to future tuning rolls for distance to the transmitter. A *successful* aiming roll gives the exact direction to the transmitter. Finding the distance as well requires *triangulation* (above).

If a transmitter's operator is actively seeking to avoid interception, any of these tasks becomes a Quick Contest of Electronics Operation (EW).

Triangulation

Triangulation determines the location of a transmitter or other source of radio waves by comparing the angles from two or more radio direction finders (p. 48) and finding where lines drawn from them intersect. (This is the same principle that lets binocular vision achieve depth perception.) Basic RDF systems or improvised systems require manually plotting the lines to a source; roll a quick contest of the lesser of Mathematics (Applied or Surveying) or Electronics Operation (EW)-2 vs. the Electronics Operation (EW) of the transmitter operator, with penalties for haste if the signal stays on for less than 1 minute. For a more sophisticated system such as HF/DF (p. 48), roll vs. unmodified Electronics Operation (EW), with no penalties for haste. The roll is at +6, with an added bonus for the distance between the antennas, and a penalty for the distance to the source (both taken from the *Size and Speed/Range Table,* p. B550). If the signal source isn't being concealed, the listener's roll is unopposed.

Standard triangulation uses three directional antennas in an equilateral triangle. A system with two antennas is at -2, since the antennas may be at a bad angle; a system with one antenna can't determine distance at all! If a transmitter continues to operate, a single antenna can be moved to a new location and the two readings can be plotted in the same way; a roll vs. Hobby Skill (Amateur Radio) can do this in a "transmitter hunt."

On a victory (for an opposed roll) or a success (for an unopposed roll), the operator has located the general area of the transmitter, subject to the rules for scatter (p. B414). The magnitude of the scatter is 20% of the range to the transmitter on a success or victory, reduced to 10% for a margin of 2, and to 5% for a margin of 4. With a margin of 6, or a critical success, the operator determines the exact location. On a failure or defeat, the location can't be determined. On a critical failure, an entirely wrong location is identified.

Interpreting the results of signals intelligence often involves *traffic analysis*, an optional specialty of Intelligence Analysis. This can identify chains of command by analyzing the flow of messages; track changes of location of stations; or recognize heightened activity levels that could indicate tactical operations in progress. Traffic analysis does not require knowing the content of messages.

SIGINT Gear (TL7)

A radio-interception facility has a variety of equipment, depending on TL.

Intercept Unit (TL6). A specialized receiver designed for picking up radio communications. Treat as a large radio (p. 27) with receive-only (p. 28) and such features as precision tuning, a signal-strength meter, and a large antenna array. At TL8, add computer-controlled frequency scanning. Gives +4 to monitor routine traffic; standard equipment for other operations. ×5 cost. [1905] 1918.

Radio Direction Finder (TL6). A radio with receive-only (p. 28) equipped with a directional antenna (p. 28). Can be improvised with a loop of wire or a dipole (two rigid metal rods pointing in opposite directions), giving -5 to skill rolls. Radio direction finding (RDF) indicates the direction to a transmitter, but not its distance; an improvised system doesn't indicate which of two opposite directions the transmitter is in. Using a transmitter of known location as a beacon takes 1 minute, requires an unopposed roll vs. Electronics Operation (Comm or EW), and gives +1 to Navigation (Air, Land, or Sea). Can also be used to search for concealed transmitters. ×2 cost. [1902] 1919.

HF/DF (TL7). High-frequency direction finding, or "huff-duff." An improvised version can be set up with two RDF systems and an oscilloscope (p. 11). Determines the direction of a signal source almost instantly, avoiding penalties for haste. ×5 cost. [1926] 1942; cutting edge (p. 8) until 1945.

Spectrum Analyzer (TL7). See p. 11. Roll Electronics Operation (EW) at +4 to identify an active frequency.

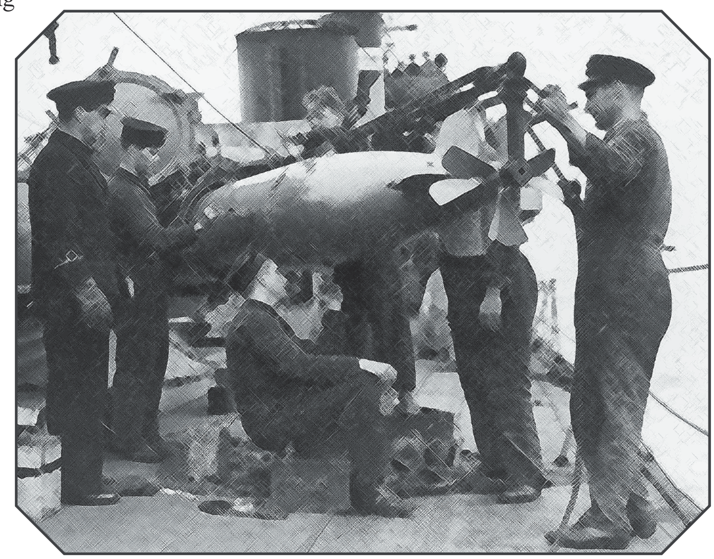
Digital Spectrum Analyzer (TL8). An inexpensive handheld device usable in the field to detect radio transmitters; roll Electronics Operation (EW) at -2. Rechargeable/10 hours. $200, 0.5 lb. 2000.

Encryption (TL5)

As early as the Civil War, military forces tapped each other's telegraph lines. To prevent this, text messages were *encrypted*, at first manually. After 1900, cipher machines became available (***High-Tech,*** p. 211). Sending encrypted text is more difficult than sending plain text, since errors aren't obvious ("hte" could be what was meant just as well as a missent "the"): -4 to Electronics Operation (Comm) skill. This penalty can be reduced or avoided by taking extra time (p. B346).

Decryption (TL7)

Decrypting intercepted coded messages became important to military strategy during World War II. At first, specialized electromechanical machines, known as *bombes,* carried it out. These gave +1 to breaking codes created on Enigma machines (see *Cipher Machines*, High-Tech, p. 211), starting in 1940 (TL7). The bombe is a stationary device (1 ton and 100 cubic feet) and counts as a Complex invention. In 1944, Colossus, a dedicated vacuum-tube macroframe (see p. 37), came into use, giving +2 to Cryptography for codebreaking. This was followed by general-purpose digital computers (p. 13), which are now standard equipment for Cryptography (p. B186).



Fuzes and Guidance

Electronics began playing a role in munitions (mines, shells, missiles, and the like) during World War II, allowing more effective use of conventional projectile weapons.

Fuze (TL7)

A *fuze* (in American usage) is a complex mechanism for setting off an explosive charge automatically. In 1943 (TL7), a variety of electronic fuzes were developed. Specified weights are for TL7 fuzes; halve the weight after 1980 (TL8).

Impact Fuze: Sets off the explosive charge on impact with the target. To avoid premature detonation, it has a safety wire that's removed just before firing, after which the projectile arms itself, with a short delay. $25, 2 lbs.

Proximity Fuze: Originally called the "VT fuze" (for *variable time*) to avoid revealing how it actually worked. It contains a compact radar system that can detect a target up to 25 yards away and set off an explosive charge at a specified distance. $200, 2.5 lbs.

Time Fuze: A much more rugged version of the electronic watch (p. 39). Can be set for any time after firing up to 3 minutes. An improvised version can be made with a clock and a few electronic parts on a roll vs. Explosives (Demolition). $25, 2 lbs.

Guided Weapons (TL7)

Guided weapons are steered toward a target by a human operator (see pp. B412-413). Experimental weapons were designed during World War II, but actual use began in 1956. A standard design has a television camera in the missile transmitting to a screen watched by the operator, who uses a joystick (p. 49) to steer the missile. Communication is maintained by a wire trailing behind the missile, or, after 1962, by radio (see *Spread Spectrum,* pp. 46-47).

Homing Weapons (TL7)

Homing weapons are steered toward a target by internal systems that operate independent of the operator (p. B413). The missile attacks with a skill of 10, plus its Acc if the operator succeeded in the Aim roll. The attack roll depends on the missile's ability to detect the target by one of the following methods (a missile may have a second detection system as backup).

Acoustic: A torpedo homes in on the sound signature of a ship or submarine. Advanced models can target propulsion and steering systems (treat as vital areas; see p. B555).

Infrared: A missile homes in on a target's hot exhaust. It can also track a warm hull with -2 to effective skill.

Lidar: A missile locates a target with lidar and tracks it. See also *Laser Designator* (below) for passive systems that depend on illumination of the target by the launch system.

Radar: A missile locates a target with radar and tracks it.

RDF: A missile homes in on radio emissions on a specified frequency. This is often used as backup, with the emissions coming from a target's radar-jamming emissions.

Laser Designator (TL7)

First used in the Vietnam War, this system combines guidance and homing. The missile is designed to seek a point of light projected by a laser. The operator or a forward observer keeps the point on the desired target with a series of Aim maneuvers. 2×M/24 hours or automotive power. $750, 12 lbs. [1968] 1972.

Electronic Weapons

Electrical and electronic devices can be used as weapons, delivering electric current or electromagnetic radiation to incapacitate or injure a foe. See the *Weapons Tables* (pp. 50-51) for details on their effects.

Push the button
Pull the switch
Cut the beam
C'mon, make it march

– Jefferson Starship,
"Mau Mau (Amerikon),"
inspired by Robert Heinlein,
Methuselah's Children

Electric Stunners

Electric current is mainly used to cause pain and incapacitation – both because it *can* do so with little chance of lasting injury (if used properly) and because lethal electric shock takes a lot of energy (both capacitors and batteries are inconveniently heavy ways to store energy). Most electrical weapons deliver a series of brief pulses at high voltage. The pain from these makes them an effective adjunct to Interrogation (counted as torture, giving +6) or Intimidation (+2, if the subject knows what the device is).

Cattle Prod (TL6). A device primarily designed for controlling the movement of large animals. Causes localized burning damage and moderate pain that the animal tries to avoid by moving away. +2 to Animal Handling. Date of invention uncertain; listed dates range from 1890 (by John Burton) to 1930 (by Robert Kleberg). 6×S/2,000 uses. $50, 2 lbs.

Taser (TL7). A ranged stunner that fires two darts connected to a power source. Minimum range is 1 yard, to allow the darts to spread. Shaped like a large flashlight and includes a flashlight (p. 22) with a 5-yard beam. Uses smokeless powder as a propellant; legally categorized as a firearm in 1976. S/100 seconds. $350, 2 lbs. Cartridges are $16, 0.1 lb. 1974.

Handheld Stun Gun (TL8). A handheld weapon that delivers electric shocks at close range. Can be used without special training. 2×S/2,000 uses. $25, 0.5 lb. 1983.

Stun Baton (TL8). A stun gun built into a light baton, giving increased reach. 2×S/2,000 uses. $60, 1.5 lbs. 1994. Can be combined with a rugged flashlight (p. 22).

Taser (TL8). Uses air cartridges as a propellant. XS/20 seconds. $400, 1.1 lb. Cartridges are $30, 0.25 lb. 1994.

Jammers

A *jammer* is directed not against personnel, but against electronic communications and/or sensors. Requires a roll vs. Electronics Operation (EW). A Tesla coil (p. 12) or spark-gap transmitter (pp. 28-29) can be adapted for jamming at -2 to Electronics Operation (EW) with 4 hours either in a workshop, or using a tool kit and a Scrounging roll.

Jammers come in two varieties: broad-spectrum and selective. A *broad-spectrum* jammer spreads its output over an entire frequency band. Anyone in the affected area must roll vs. Electronics Operation (Comm) at -2 to receive a signal; at up to 10× the jammer's range, this roll is unmodified. A *selective* jammer puts all its output onto a single frequency. If the frequency is known and fixed, this requires an unopposed Electronics Operation (EW) roll; otherwise, it requires a Quick Contest of Electronics Operation (EW). A spectrum analyzer (pp. 11, 48) gives +4 to Electronics Operation (EW) skill; each 10% of increased range beyond the transmitter's effective range (see *Radios*, pp. 27-28) gives -1. Success indicates that the jamming is successful, giving -4 to Electronics Operation (Comm) to receive a signal, or -2 at up to 10× the jammer's range.

Large Jammer (TL6-8). A large jammer is normally operated in a fixed location with major appliance power. Treat it as a large radio (p. 27) with ×0.5 cost and ×2 weight.

Portable Jammer (TL6-8). A portable jammer can be treated as a medium radio (p. 27) with ×5 power consumption (or automotive or better power), ×0.5 cost, and ×2 weight.

Radar Jammer (TL7). A jammer tuned to radar frequencies, operating to "blind" the radar system; often carried in EW aircraft to provide cover for other aircraft. Effectively similar to a radio jammer, but works against Electronics Operation (Sensors) rather than Electronics Operation (Comm). Radius 15 miles. Major appliance power. $50,000, 200 lbs. 1941. At TL8, double radius and halve weight.

Cell-Phone Jammer (TL8). A special-purpose system that interferes with all cell-phone calls within a 15-yard radius. A system with double the radius has 4× cost and weight. This functions as a broad-spectrum jammer for cell-phone frequencies. Rather than requiring an Electronics Operation (Comm) roll to use the phone, overcoming the jamming requires a Hearing roll at -2 to make out what is being said. Automotive or household power. $500, 5 lbs. 1991.

Radar Spoofer (TL8). An advanced variation on radar jamming, based on digital radio-frequency memory. Rather than simply blinding a radar system, it records its output and sends back a modified version that gives a misleading impression of a target's location and size. Requires a Quick Contest of Electronics Operation (EW) vs. Electronics Operation (Sensors). Treat as a TL8 radar jammer with ×2 cost. [1975] 1999.

Psychotronics

In ***GURPS,*** "psychotronics" is a specialty of Electronics Operation, Electronics Repair, and Engineer. This specialty is concerned with technological devices with psionic effects (as discussed in ***GURPS Psi-Tech***). In the real world, it's one name for the belief in electromagnetic techniques for beaming thoughts into people's brains, also known as *electronic harassment*. In ***GURPS*** terms, this belief is usually a Delusion (p. B130), which may inspire such actions as visiting conspiracy-theory sites or wearing metal-foil hats. The GM could include psychotronics in Hidden Lore (Conspiracies) (p. B200) if it is appropriate to the campaign.

Shielded Cap (TL8). A commercially manufactured garment that covers the skull with a screen against radio waves. $30, 1.2 lbs. 2000.

EMP

Electromagnetic pulse (EMP) is *high-powered* electromagnetic radiation. It doesn't just create radio noise; it stops electronic devices from operating and sometimes destroys them. EMP from nuclear explosions is the best-known form (see ***High-Tech,*** p. 196), but smaller non-nuclear devices with reduced range and less severe effects are possible.

NNEMP (TL8). A non-nuclear EMP device that disables electronic devices within 220 yards. One proposed design, the flux compression generator, discharges a bank of capacitors into coils that are then compressed by an explosive charge (set up using Explosives (Demolition) skill), creating an intense magnetic field. Such devices, nicknamed "E-bombs," are destroyed by being used. Roll vs. HT for each device (HT+3 for Hardened devices and for purely electrical devices without electronic components). On a failure, the device shuts down and must be repaired before it can work again; repair rolls for non-Hardened electronic devices are at -6. Average complexity. [1951].

Directed Energy Weapons

Science fictional accounts of directed energy weapons go back at least to the Martian "heat-ray" in *The War of the Worlds*. Real-world designs began to appear in the 1980s, though few have gotten past the prototype stage. Such weapons are often intended to incapacitate without permanent harm; a United Nations protocol of 1995 banned laser weapons with permanent blinding effects.

Dazzler (TL8). A laser weapon designed to blind humans or animals temporarily. The model described is relatively low-power and short-ranged, and is available for civilian use. Rechargeable/1 day. $1,000, 1.5 lb. [1982] 2010.

Active Denial System (TL8). A transmitter operating at millimeter wavelengths. Aimed with a video screen and joystick. The beam from its antenna heats living tissue to a depth of less than 1/20", causing painful burning sensations but no injury. The number of shots reflects the time required to select a new target; it can continue to fire as long as it's supplied with power. Prototype versions weigh 4,500 lbs. and can be transported on a truck or similar vehicle. Complex complexity. Major appliance power. [2007].

Weapons Tables

These tables collect statistics for melee weapons and ranged weapons discussed throughout this supplement. Terms and notation are as defined on pp. B268-271.

Melee Weapons Table

TL	*Weapon*	*Skill Penalty*	*Damage*	*Reach*	*Parry*	*Weight*	*ST*	*Page*	*Notes*
BRAWLING or DX									
8	Stun Gun	–	HT-3(0.5) aff	C	No	0.5	2	49	[1]
KNIFE (DX-4, Force Sword-3, Main-Gauche-3, or Shortsword-3)									
6	Arc Welder	-2	3d burn	C	No	2.25	3	21	
6	Power Drill	-2	1d+2(2) pi++	C	-1U	4.5	10	24	[2, 3]
6	Soldering Iron	-1	1 point burn	C	-2	1.25	7	14	

Melee Weapons Table (Continued)

TL	Weapon	Skill Penalty	Damage	Reach	Parry	Weight	ST	Page	Notes
SHORTSWORD (DX-5, Broadsword-2, Force Sword-4, Jitte/Sai-3, Knife-4, Saber-4, Smallsword-4, or Tonfa-3)									
6	Cattle Prod	–	1d-3 burn	1	0	2	3	49	
	linked		HT-3 aff						[4]
7	Stun Baton	–	sw-1 cr	C, 1	0	1.5	6	49	
	or	–	thr-1 cr	C, 1	0	–	6		
	linked		HT-1(0.5) aff						[1]
TWO-HANDED AXE/MACE (DX-5, Axe/Mace-3, Polearm-4, or Two-Handed Flail-4)									
6	Circular Saw	-3	sw+3(2) cut	1	-1U	20	11‡	24	[5]
	or		sw+3(5) cut						[6]
7	Compact Circular Saw	-2	sw+1(2) cut	C	-1U	6.5	10‡	24	[5]
	or		sw+13(5) cut						[6]

Notes

[1] On a failed HT-3 roll, the victim is stunned for as long as the weapon is in contact plus (20 - HT) more seconds, and then must roll vs. HT-3 to recover.

[2] May get *stuck* (p. B405). Can be freed in one turn without a ST roll by reversing the motor.

[3] Use of smaller drill bits (1/4" or less) causes pi+ damage.

[4] On a failed roll, the victim experiences Moderate Pain (Severe Pain if the device is applied to the face or groin) lasting 1 minute per point by which the roll was failed.

[5] Crippling damage to a limb amputates it.

[6] When an abrasive diamond blade is used.

Ranged Weapons Table

TL	Weapon	Skill Penalty	Damage	Acc	Range	Weight	RoF	Shots	ST	Bulk	Rcl	Page	Notes
BEAM WEAPONS (PISTOL) (DX-4 or other Beam Weapons-4)													
8	Dazzler	0	HT-5 aff	5+1	75/750	1.5	1	86,400	2	-2	1	50	[1, 2]
8	Laser Pointer	-1	HT-2 aff	5	2/20	neg.	1	50,000	2	0	1	21	[1, 2, 3]
BEAM WEAPONS (PROJECTOR) (DX-4 or other Beam Weapons-4)													
8	Acoustic Hailing Device	0	HT-3 aff (30 yd)	7	2/30	15	1	480	10†	-5	1	32	[4]
GUNNER (BEAMS) (DX-4 or other Gunner at -4)													
8	Active Denial System	–	HT-5 aff (5 yd)	5	300	10,000	1	1(2)	250M	-15	1	50	[5]
GUNS (PISTOL) (DX-4 or most other Guns at -2)													
7	Tasertron TE-76	–	1d-3 pi-	0	5	2/0.1	1	1(5)	8	-2	2	49	
	follow-up		HT-3(0.5) aff										[6]
8	Air Taser Model 34000	–	1d-3 pi-	0	5	1.1/0.25	1	2(3i)	7	-2	2	49	
	follow-up		HT-3(0.5) aff										[6]

Notes

Do not look into laser beam with remaining eye.

– Joke warning sign

[1] This is a Vision-based affliction that causes blindness for minutes equal to the margin of failure if the target's eyes have adapted to twilight (-2 darkness penalty) or darker conditions.

[2] Nictitating Membrane gives +1/level to the roll to resist; obscuring conditions (fog, smoke, etc.) give +1 per -1 Vision penalty; Protected Vision gives +5.

[3] For a green laser pointer, Range is 10/100.

[4] On a failed roll, the victim experiences Moderate Pain for the duration of the sound output. After 1 minute of continued exposure, they suffer tinnitus lasting 1 minute per point of failure, making them Hard of Hearing. If they then fail a HT roll, this continues for 1d months; on a critical failure, the condition is permanent. Protected Hearing gives +5 to resist these effects, and prevents permanent hearing loss; Deafness grants immunity to them.

[5] On a failed roll, the victim experiences Agony as long as they remain in the area of effect, and for 1 second afterward; they have the ability to flee.

[6] On a failed roll, the victim is stunned while the trigger is depressed and for 20-HT seconds thereafter, and can then roll vs. HT-3/HT-5 to recover.

INDEX

There is nothing wrong with your television set. Do not attempt to adjust the picture.

– Opening credits, ***The Outer Limits***

"You belonged to the technocratic elite even before you picked up that book," Kivistik said. "The ability to wade through a technical text, and to understand it, is a privilege."

– Neal Stephenson, ***Cryptonomicon***