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MATERIALS & TOOLS

// **The aesthetic and expressive qualities of every crafted object begin with the choice of materials. This chapter is an introduction to conductive and smart materials, industrial materials, electronic components, and the tools you need to begin crafting with these materials.**

New conductive and smart materials present exciting creative possibilities for making objects that are animated, dynamic, and responsive. Smart materials react to their environments — changing shape, shifting color, emitting light, and even producing sounds. New conductive materials, such as inks, threads, and textiles, allow you to easily weave simple electronics into fabrics. By incorporating electronic components and simple circuits into your crafts, you can give your projects a central nervous system capable of "sensing," "expressing," and even "thinking." Even the most basic circuit holds lyrical and emotive potential.

Raw, **industrial materials** from cardboard to industrial felt offer yet another palette to expand your crafting repertoire. A stroll down the aisles of a hardware store can be as inspirational as rummaging through a textile scrap bin. In order to explore this new way of crafting, the traditional crafting workbench is redefined with the addition of a few new **tools**. Your wire cutters will become just as important as your thread snippers as you shift your vintage sewing machine to make room for a new soldering station.

Incorporating **electronics** into your projects and crafting with smart materials is just like learning any other craft: through experimentation and making, you easily become familiar with each material's and each component's unique personality; its technical and physical characteristics as well as its visual and tactile qualities.

NEW CONDUCTIVE AND SMART MATERIALS

Embroidered circuits, pattern-shifting textiles, and hand-sculpted plastic toys are just a few examples of the creative possibilities offered by the seductive world of new conductive and smart materials.

The extraordinary, almost magical, characteristics of these materials lend themselves to fashioning objects and wearables that are artful, quirky, humorous, and poetic. These high-tech materials are a fascinating yet relatively unexplored medium for experimental crafting.

WHAT EXACTLY MAKES THESE MATERIALS SO "SMART"? » Smart or "intelligent" materials are responsive and dynamic. » They have the ability to change color, shape, and size in response to their environments (touch, sunlight, and pressure, for example). » Some even have the capability to remember and return to their original state. » From threads and textiles that shift color to piezoelectric materials that can generate sound with the application of a small current, these materials offer a range of possibilities for crafting objects with an autonomous, secret life of their own.

» Less dynamic but equally as relevant are new conductive materials such as inks, threads, textiles, and even epoxies, which now present an unorthodox fashion to assembling electronic circuitry. Circuits can now be colorful and decorative, embroidered, inked, or knit. They can be exposed, rather than hidden, as a fashion statement or design aesthetic. With the sewing machine as a viable substitute for the soldering iron, this ability to fashion technology enables us to craft a new generation of objects that are interactive, unusual, and fashion-conscious.

Following are concise descriptions, applications, and illustrative examples for a number of new conductive and smart materials to give you a jump start on crafting smart.

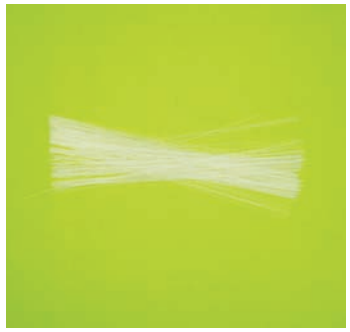
Electroluminescent (EL) Ink, Film, and Wire

Composition
» Typically comprised of a dielectric layer between two conductive electrodes and a layer screen-printed with phosphor powder.

Properties
» A thin and flexible film or wire coated in phosphor that emits a bright light when electricity is applied, using very little current.
» EL film and wire run on AC voltage. An inverter is typically used to run the film or wire on DC voltage.

Applications
» Typically used for backlighting.
» Film and wire can be used to illuminate curved and 3D surfaces.
» Wire is extremely flexible and can be used to create decorative shapes.
» Inks used to screen-print glowing designs onto polyester or film substrates.

Fiber Optics



Composition
» Plastic or glass cables capable of transmitting light.

Properties
» Transmit light from one end of the cable to the other, essentially acting as a tunnel through which light can travel over a distance.
» Can be bundled together and, because they are lightweight and flexible, send a beam of light from one point to another.
» Transmit light, not electricity, so the light source is isolated from the output.

Applications
» Offer the flexibility to create novel ambient light projects.
» Can be woven into textiles and other heat-sensitive materials.
» Can even be used to bring natural sunlight into indoor environments.

Heat-Shrink Tubing

Composition
» Polyolefins.

Properties
» Flexible tube that shrinks when heated.
» Comes in a variety of colors and diameters.

Applications
» Used to insulate raw wires and electronic components.

LEDs (Light-Emitting Diodes)

Composition
» Gallium compounds.

Properties
» Small light source capable of emitting bright light.
» Consume very little power, do not emit much heat, and are programmable.
» Come in a variety of colors, shapes, and sizes.

Applications
» Can be incorporated to create programmable, ambient, and decorative lighting.

Magnetic Paint

Composition
» Lead-free, water-based latex primer paint mixed with metal particles.

Properties
» Creates a magnetically receptive surface, turning any material (wood, plastic, textiles, etc.) into a surface to which magnets are attracted.

Applications
» Can be used for interior design, converting walls and furniture into magnetic surfaces.

Phosphorescent (Glow-in-the-Dark) Materials

Composition
» Zinc sulfide and magnesium sulfide crystals.

Properties
» Materials such as inks, paints, and thread that emit light over time after they absorb invisible UV light from sunlight or other UV sources.
» Dramatically come to life at night or in low lighting conditions after they have gathered light energy during the day.

Applications
» Can be incorporated to create luminous skins and decorative textures.
» Traditionally seen in glow sticks and glow-in-the dark paint.

Photochromic Inks and Dyes (Ultraviolet)

Composition
» Typically available as powdered crystals comprised of ultraviolet (UV)-sensitive pigments that must be dissolved in the appropriate ink for application.

Properties
» Change from clear to colored when exposed to sunlight, blacklight, or other UV sources. Revert to their original state once removed from the UV source.
» Can change from one solid color to another when mixed with a permanent, colored ink.

Applications
» Can be stenciled, sprayed, and silk-screened onto various media, including paper, plastic, wood, glass, and textiles. For printing purposes, a low mesh screen (between 85–110 threads/inch) is recommended.
» Can be used to create dynamic patterns that change in accordance to lighting changes in their environment.

Piezoelectric Materials

Composition
» Lead zirconate titanate.

Properties
» When subjected to slight mechanical stress (sound, motion, force, or vibration), can generate electrical charges. Inversely, when an electrical charge is applied, these materials can generate a physical force, often enough to be converted into sound. This makes them both sensors and *actuators** at the same time.

Applications
» Serve as excellent environmental sensors that can be used to output and sense sound, motion, and vibration, such as knocking on a surface, for example.
» Coupled with other environmental sensors such as solar cells, can be used to convert light to sound, motion, or vibration, for example.

* An actuator is a device that transforms an electrical input signal into action.

Polymorph Plastic

Composition
» Caprolactone polymer or Oxepanone polymer.

Properties
» A thermoplastic that becomes moldable at around 62° C.
» Becomes pliable and easily hand-sculpted when immersed in hot water or heated using a hair dryer. Returns to a rigid state when cooled.
» Can be reheated and thermo-formed indefinitely.
» Available in a variety of colors.

Applications
» A remarkable model-making and prototyping material that can be rolled into flat sheets, sculpted into 3D forms, and used to create molds.

Shape Memory Alloy (SMA or Muscle Wire)

Composition
» A combination of two or more metallic elements, the most popular being Nitinol, composed of nickel and titanium.

Properties
» Unique metals that remember their shape.
» Exhibit hardness and elasticity properties that change radically at distinct temperatures.
» Unlike typical metals, contract when heated and return to their original state when cooled.
» Some SMA wires can be bent into a particular shape by heating at the transition temperature; will then return to their original form when cooled.

Applications
» Can be used to trigger movement.
» Can be woven into textiles.
» Can make fabrics shrink or curl with the application of a small current.
» In robotics, used to animate robots, acting as the robot's muscles.

Solar Cells

Composition
» Made of a refined, highly purified form of silicon.

Properties
» Convert light energy (typically from the sun) into electrical energy.

Applications
» An excellent sustainable and renewable power source for projects.
» Offer the advantage of acting as light sensors, able to distinguish between light and dark and between different times of day.

Thermochromic Inks (Temperature-Sensitive)

Composition
» Made from various organic and inorganic compounds.
» Pigments must be dissolved in the appropriate ink type for application.

Properties
» Change from one color to another or from color to translucent at a specific temperature.
» Have the ability to infinitely shift color.

» Three main types:
» *low* reacts to cold
» *body* reacts to touch, breath, and body heat
» *high* reacts to hot liquids and air

Applications
» Can be stenciled, sprayed, and silk-screened onto various media, including paper, plastic, wood, glass, and textiles. For printing purposes, a low mesh screen (between 85–110 threads/inch) is recommended.
» Can be used to create dynamic patterns that change in accordance to their environment (for example, to fluctuations in temperature).

INDUSTRIAL MATERIALS

Raw industrial materials — from cardboard to industrial felt — offer yet another palette to expand your crafting repertoire.

Knowing these materials and their capabilities can make a stroll down the aisles of a hardware store as inspirational as rummaging through a textile scrap bin. Here is a list of industrial materials used in a few of the projects.

A. Cotter Pin
A metal fastener with two prongs. Can be repurposed to make flexible battery holders for coin cell batteries.

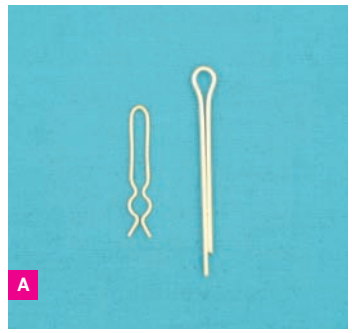
B. Copper Tape
A thin, conductive foil tape with conductive adhesive. Comes in handy when working with broken solar panels.

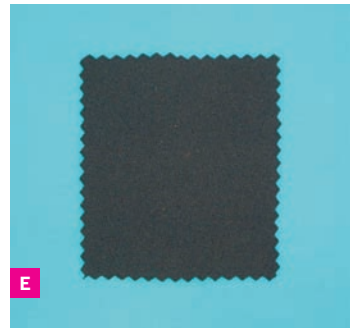
C. Flame-Retardant Fabric
Fabric with fire-resistant qualities. An excellent medium for working electronics into textiles for the home. Typically available in wide widths; styles range from velvet and velour to basic canvas.

D. Industrial Felt
A dense, texture-rich fabric made from 100% wool, a renewable and environmentally friendly material that can be used to make virtually anything, from furniture to jewelry. Raw wool felt is typically white or grey, but designer wool felts are available in a variety of colors.

E. Neoprene
A synthetic, rubber fabric commonly used in protective gear and sportswear. Abrasion-resistant, chemical-resistant, waterproof, and elastic, making it an ideal material to craft tech-infused sportswear.

F. Zip Tie (aka Cable Tie)
A fabric or plastic fastener used to bundle loose electric cables and wires together.





ELECTRONIC COMPONENTS

Electronics are everywhere, from mobile phones and computers to sensing athletic shoes. These sophisticated devices all employ some type of integrated circuit along with a handful of basic electronic components.

» Integrated circuits, or ICs, are the basic building blocks of modern electronics. Bug-like in appearance, ICs are essentially complex circuits etched onto silicon and mounted onto chips. Because all the hard work has already been done for you, they make building sophisticated electronic circuits from scratch a breeze. You will be using ICs such as the Hex-Schmitt inverter in some of the advanced projects and various basic components for the rest.

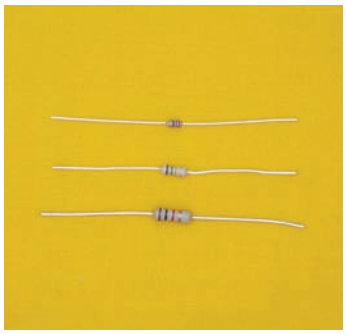
» Before you start working with ICs or any other electronic components, you need to know what they look like and what they do. Every type of electronic component comes in several variations with different specifications. Even components within the same family may have a dramatically different appearance, and ones that look identical may have very different specifications.

» It is important to pay attention to the *operating values* and the *package type* of each component. Typically, the accompanying specifications and datasheet of each component tell you its minimum, maximum, and normal operating values for voltage and current, and its power ratings. These values should not be exceeded, to prevent damaging your component.

The following pages contain a general overview of the electronic components you will be using to construct your circuits. The more circuits you build, the easier it will become to learn the properties and functions of each.

Components Index

Fixed-Value Resistors



Description
» A cylindrical core with two conductive metal leads, which are not polarized (no negative and positive side).

Function
» To limit the current and divide voltage.

Operating Value
» Two ratings:
» Resistance value rated in ohms (Ω) and a power rating in watts (W).
» Resistors have color-coded bands to help designate their resistance value.

Refer to Chart 1.

Capacitors

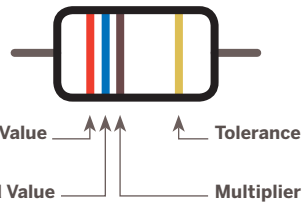
Description
» An electrical device with conductive plates separated by an insulating material called a *dielectric*.
» Most common types are:
» mica
» ceramic
» plastic-film
» electrolytic
» *Electrolytic capacitors* are polarized, having one positive and one negative lead, and they resemble little barrels.

Function
» Essentially a temporary battery, capable of storing electrical charge.

Operating Values
» Two ratings:
» A *voltage rating*, which specifies the maximum voltage that can be applied without damaging the component.
» A *capacitance value*, which is rated in farads and is typically printed on the capacitor itself.

Refer to Chart 2.

1 RESISTOR COLOR CODE

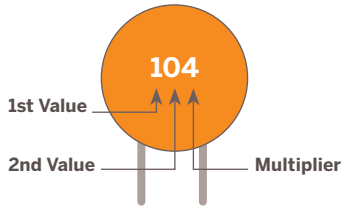


	Value	Multiplier	Tolerance
■	0	1	–
■	1	10	±1%
■	2	100	±2%
■	3	1K	–
■	4	10K	–
■	5	100K	±0.5%
■	6	1M	±0.25%
■	7	10M	±0.1%
■	8	100M	±0.05%
□	9	1000M	–
■	–	1/10	±5%
■	–	1/100	±10%
☒	–	-	±20%

The color of the first band indicates the first digit, and the color of the second band indicates the second digit. The third band indicates the value that the first two digits need to be multiplied by.

IN THE EXAMPLE SHOWN:
The first is 2, the second 6, multiplied by 10:
26×10 = 260Ω resistor.
The fourth band is the tolerance or precision of the resistor.

2 CAPACITOR NUMBER CODE



NOTE: For capacitors less than 100pF, only a two-digit number is printed on the capacitor, or a two-digit number followed by a "0". For example, a 55pF capacitor may be marked as "55" or "550".

To determine the value of a capacitor:

The multiplier stands for how many zeros to add to the first two values.

The result is the *capacitance value* in picofarads (pF).

IN THE EXAMPLE SHOWN:
10 with a multiplier of 4 (adding 4 zeros) = 100,000pF or .1μF (microfarads).

SWITCHES

Description

» Used to open (disconnect) and close (connect) circuits by either mechanical or electronic means.

Function

» Switches generally fall into the following six categories:

1. Single-pole single-throw (SPST)
2. Single-pole double-throw (SPDT)
3. Double-pole single-throw (DPST)
4. Double-pole double-throw (DPDT)
5. Push-button (PB)
6. Rotary

» The term *pole* refers to the movable arm in a switch that either opens or closes a circuit. A single-pole switch controls one circuit, while a double-pole switch controls two.

» The term *throw* describes the number of closed positions. A double-throw switch actually has three connections: the right and left close the circuit, and the middle position opens the circuit.

» Switches are also referred to as *normally open* (NO) or *normally closed* (NC). In a normally open switch, the contacts are not touching, so the circuit is open or disconnected. In a normally closed switch, the contacts are touching, so the circuit is closed or connected. If a normally open push-button (PBNO) switch is connected to an LED, when the switch is pressed, the LED turns on, and when it is released, the LED turns off. The reverse is true with a normally closed push-button (PBNC) switch.

A. Magnetic Switch

The magnetic attraction brings the magnets together, opening or closing the circuit. Since magnets are made of alloys, they are conductive.

B. Push-Button (PB)

When pressed momentarily, connects or disconnects contact points. When released, contacts return to original position, as in a doorbell.

C. Reed Switch

Has two thin reeds of magnetic material inside a glass housing. When a magnet is brought near, the reeds magnetize and attract each other, closing the circuit. When the magnet is removed, the reeds separate and move to their original positions. Reed switches can also be normally closed (NC).

D. Tilt Switch

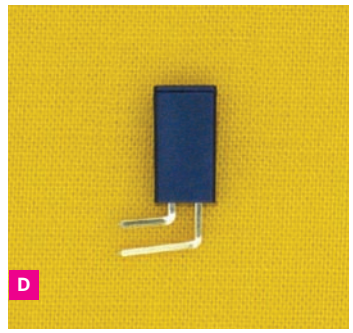
Contains either mercury, a conductive liquid, or a metal ball bearing that, when tilted at a specified angle, connects the contact points, closing the circuit.

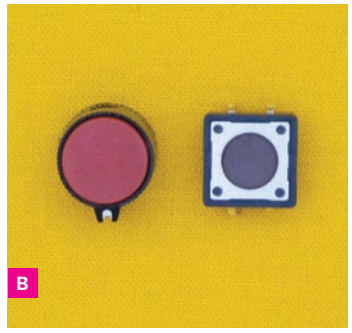
E. Toggle Switch

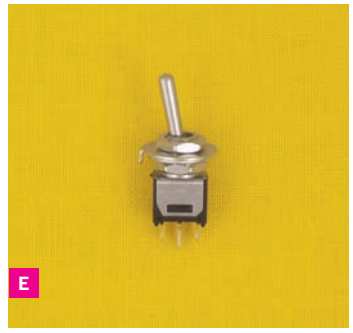
Has a projected lever or arm used to mechanically connect or disconnect contact points, opening or closing a circuit. Can have multiple sets of contact points.

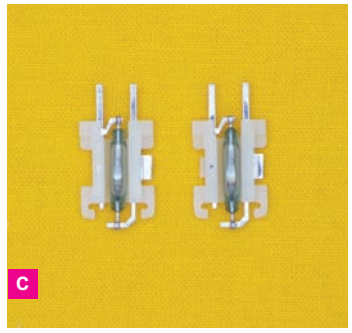
F. Whisker or Trip Switch

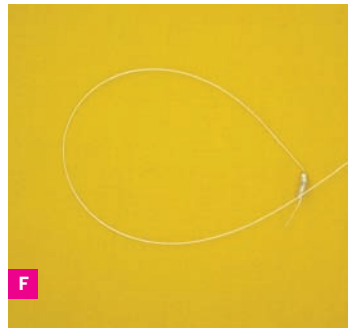
Has a thin wire extended out from the component. When lightly touched, triggers circuit to open or close.



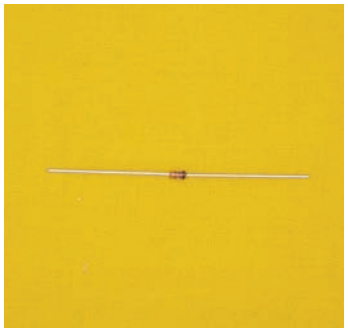








Diodes

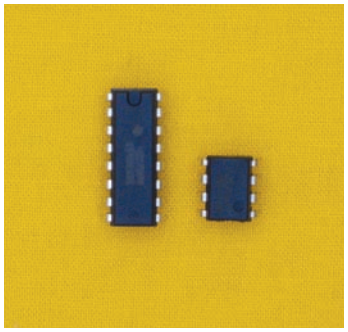


Description
» A semiconductor that allows current to flow in only one direction.
» There are several types that perform a variety of functions. The most common type is a silicon diode. Other diodes include LEDs and photodiodes, which emit light and detect light, respectively. All diodes are polarized with a positive and negative lead.

Function
» Typically used in circuits as a form of protection to maintain a fixed voltage and protect against voltage spikes.
» Also sometimes used as a voltage-sensitive switch.

Operating Values
» Two ratings:
» A *voltage* and *current rating* specifying the maximum voltage and current that can be applied without damaging the component.

Integrated Circuits (aka IC)

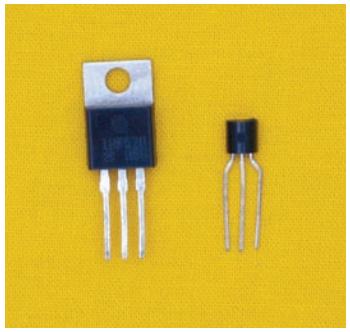


Description
» An electronic device made from semiconductor material containing transistors and other electronic components.
» Typically have several pins that need to be connected to other electronic components in a circuit.

Function
» There are countless ICs on the market that perform different functions. You must refer to the product datasheet to get a specific explanation of the application, pin diagram, and operating values.

Operating Values
» Ratings for ICs vary. Refer to the IC datasheet for the minimum, maximum, and typical operating voltage and current values.

Transistors



Description
» A semiconductor device with three *leads*: emitter, base, and collector.

» Functions to allow or restrict current flow, much like a switch, but with electricity as an actuator instead of manual movement.

» Two major types: bipolar and field-effect transistors (FETs). Unlike bipolar transistors, the leads of FETs are referred to as the gate, source, and drain.

» Bipolar transistors fall into two main categories: *NPN* and *PNP*. NPN transistors function similar to a normally open switch, and PNP transistors function as a normally closed switch.

Function
» Commonly used as a current amplifier or an electronic switch.

Operating Values
» Ratings for transistors vary. Refer to the datasheet for the minimum, maximum, and typical operating voltage and current values.

VARIABLE RESISTORS

Description
» Have a predetermined range of resistance value that can be adjusted manually or automatically, unlike fixed-value resistors.
» All variable resistors will have nonpolarized leads.

» Several types available, as detailed here.

Function
» To limit the current and divide voltage.

Operating Values
» Three ratings:
» Maximum resistance rated in ohms (Ω)
» Power rating in watts (W)
» Voltage rating in volts (V)

The power rating defines the maximum amount of current the resistor can handle. The voltage rating defines the maximum amount of voltage the resistor can handle.

A. Flex Sensor

Increases in resistance when bent in one direction.

B. Photocell (aka Light-Dependent Resistor)

Type of photoresistor that varies resistance in response to light levels, typically decreasing resistance as light levels increase. Less common are photocells that increase resistance as light levels increase.

C. Potentiometers (aka Pots)

» Variable resistors with three terminals. The outer two terminals have a fixed resistance between them, from 0 to the maximum predefined resistance. The middle terminal is connected to the wiper, which varies the resistance.
» The most common pot is *rotary*, to which a knob is usually affixed.
» *Trimpots* or *trimmers* are typically used to calibrate the resistance needed in a circuit.

D. Thermistor

» Temperature-sensitive variable resistors that convert temperature change to a change in resistance.

» Two kinds:
» One increases in resistance with an increase in temperature.
» The other decreases in resistance with an increase in temperature.

YOUR TOOLBOX

Much like any variety of crafting, you need to invest in a small number of tools to get you started. Here is a list of the essential tools to add to your toolbox as you begin working with electronics.

A. Alligator Clips
Provide a temporary electrical connection between electronic components. Each clip has two metal clamps on opposite ends connected by an insulated wire.

B. Electrical Tape
Used to insulate unshielded wires.

C. Third Hand (aka Helping Hand)
An indispensable tool used to hold electronic components and circuit boards in place while you solder. Typically equipped with two small metal clamps to grip components, and a magnifying glass.

D. Multimeter
An essential device that tells you if you have a broken or weak connection, continuity between two components, enough power, and much more.

E. Needlenose Pliers
A pair of small pliers with long, tapering jaws that end at a pointed tip. Used to grip, bend, and curl wire.

F. Perforated Board (aka Perfboard)
Pre-punched board with or without copper traces used to prototype circuits. Unlike a breadboard, electronic components are permanently soldered together.

G. Solder
A metal alloy that is melted (with a soldering iron) to join electronic components. The solder recommended for use in your projects is 60/40 rosin-core solder.

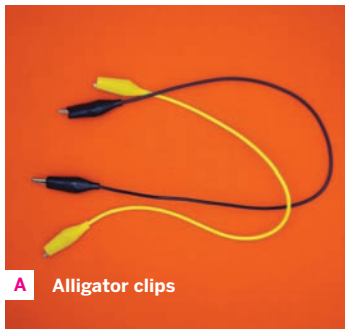
H. Soldering Station
A soldering iron is the fundamental tool used to join electronic components. A typical soldering station comes with a soldering iron, a soldering tip, a stand, and a sponge.

I. Solderless Breadboard
A handy tool used to prototype circuits and temporarily connect all the electronic components together.

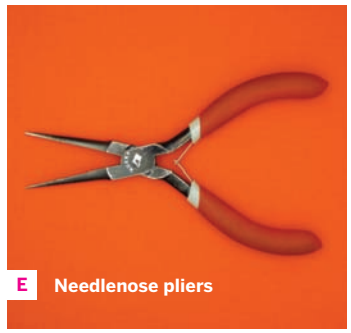
J. Wire Cutters
Used to cut wire. Can cut small wires very close up to a flat surface, more so than cutters on pliers.

K. Wire Jumpers
Used to temporarily connect electronic components on a breadboard. They come in different predetermined lengths with both ends stripped and bent at 90°.

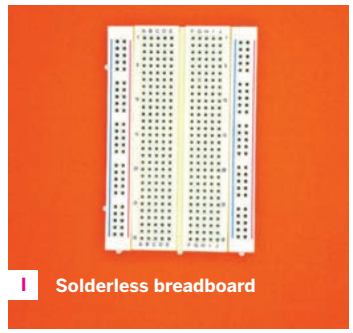
L. Wire Strippers
Used to remove the plastic insulation off of wires. Have different-sized grooved teeth for different wire gauges.



A Alligator clips

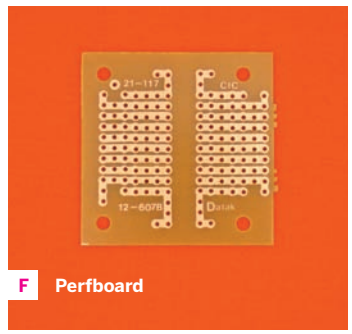


E Needlenose pliers



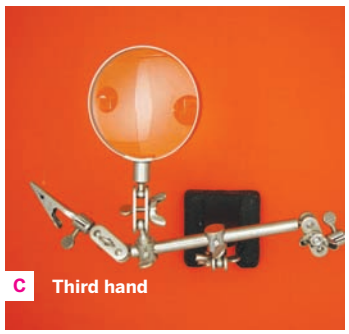
I Solderless breadboard

B Electrical tape

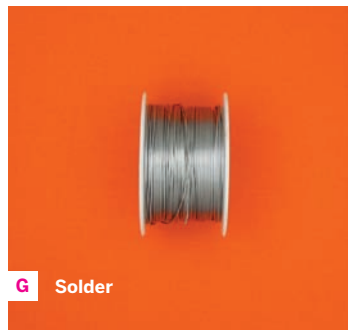


F Perfboard

J Wire cutters

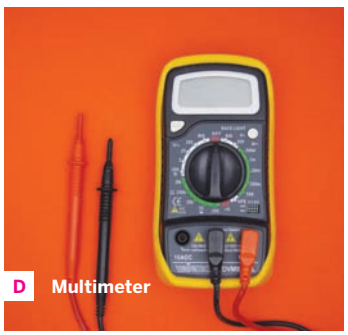


C Third hand



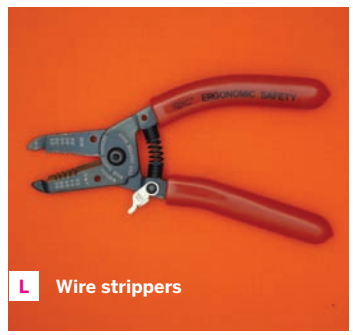
G Solder

K Wire jumpers



D Multimeter

H Soldering station



L Wire strippers