SDSU MASTERS of HOMELAND SECURITY

GEOL600 SENSOR NETWORKS

SENSOR BASICS

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Electronics
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Transistors
Thyristors
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Semiconductor Light Detectors
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LED Sun Photometer Light listener
Seeing with Sound
Electromagnetic Probe
Motion Sensor
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Extra Reading / Reference

SENSORS

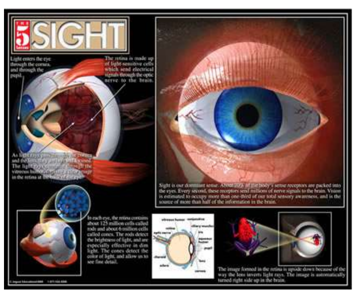
A sensor is a technological device or biological organ that detects, or senses, a signal or physical condition and chemical compounds.

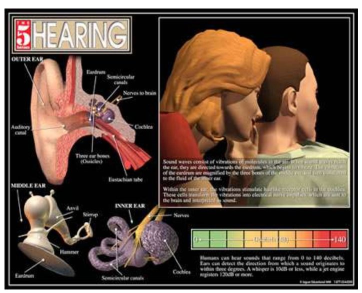
BIOLOGICAL SENSORS

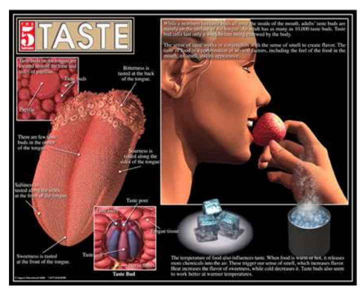
Living organisms possess sensors, most are specialized cells sensitive to:

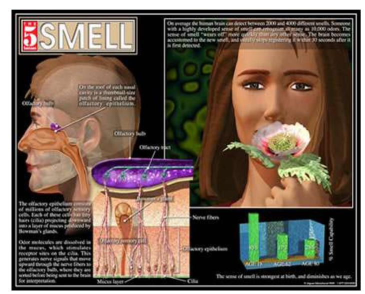
- light, motion, temperature, magnetic fields, gravity, humidity, vibration, pressure, electrical fields, sound, and other physical aspects of the external environment;
- physical aspects of the internal environment, such as stretch, motion of the organism, and position of appendages (proprioception);
- environmental molecules, including toxins, nutrients, and pheromones;
- aspects of the internal milieu, (e.g. glucose level, oxygen level, or osmolality)
- internal signal molecules, (hormones, neurotransmitters)
- differences between self /non-self proteins and pathogens

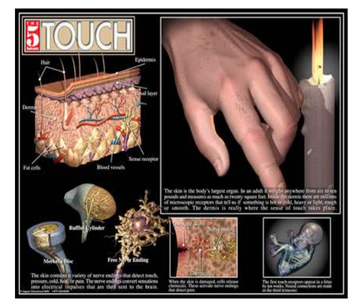
5 SENSES











http://www.jaguared.co.uk/acatalog/senses.html

ARTIFICIAL SENSORS

Most sensors are electrical or electronic, although other types exist. Sensors are either direct indicating (e.g. mercury thermometer) or are paired with an indicator through an ADC so that values sensed are human readable. Sensors can be classified according to the type of energy they detect.

- **light**: photocells, photodiodes, phototransistors, photo-electric tubes, CCDs
- **sound**: microphones, hydrophones, seismic sensors.
- **temperature**: thermometers, thermocouples, thermistors), thermostats
- **heat**: bolometer, calorimeter
- **radiation**: Geiger counter, dosimeter
- **subatomic particle**: scintillometer, cloud chamber, bubble chamber
- **electrical resistance**: ohmmeter, multimeter
- **electrical current**: galvanometer, ammeter
- **electrical voltage**: leaf electroscope, voltmeter
- **electrical power**: watt hour meters
- **magnetism**: magnetic compass, flux gate compass, magnetometer
- **pressure:** barometer, barograph, pressure gauge, altimeter, variometer
- **gas and liquid flow**: anemometer, flow meter, gas meter, water meter
- **chemical**: ion-selective electrodes, pH glass electrodes, redox electrodes
- **motion:** radar gun, speedometer, tachometer, odometer, turn coordinator
- **orientation**: gyroscope, artificial horizon, ring laser gyroscope
- **mechanical**: position sensor, strain gauge

ELECTRONICS

Electronics is the study and use of electrical devices that operate by controlling the flow of electrons or other electrically charged particles

The main uses of electronic circuits are the controlling, processing and distribution of information, and the conversion and distribution of electric power. Both of these uses involve the creation or detection of electromagnetic fields and electric currents.
More broadly, most electronics systems fall into the category of either control systems or communication systems.

One way of looking at an electronic system is to divide it into the following parts:

Inputs - Electrical or mechanical sensors (or transducers), which take signals (in the form of temperature, pressure, etc.) from the physical world and convert them into current/voltage signals.

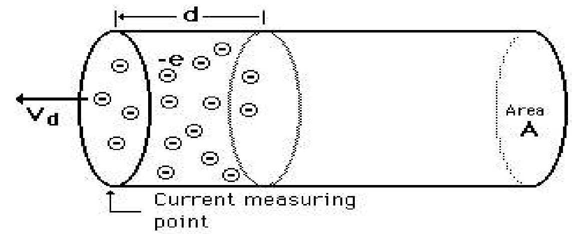
Signal processing circuits - These consist of electronic components connected together to manipulate, interpret and transform the signals.

Outputs - Actuators or other devices (also transducers) that transform current/voltage signals back into useful physical form.

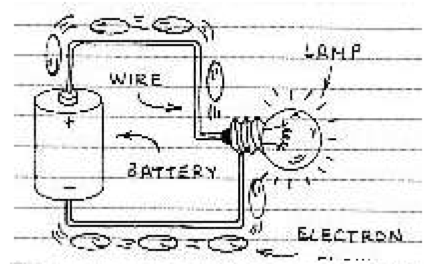
AC electronics frequencies are ultimately limited by a heat dissipation barrier at around 50 gigahertz and a plasma resonance barrier at approximately 1 terahertz.

ELECTRICAL CIRCUITS

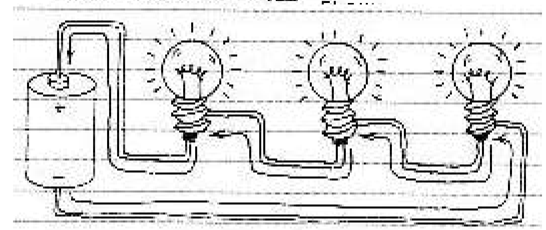
Any arrangement of components which allows an electrical current to flow.It is useful to look at electric current as the movement of multiple microscopic charge carriers with a drift velocity in a conductor.



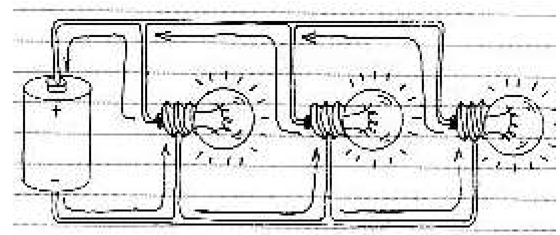
BASIC CIRCUIT
a source of electrical current (battery),
a lamp and 2 connection wires.



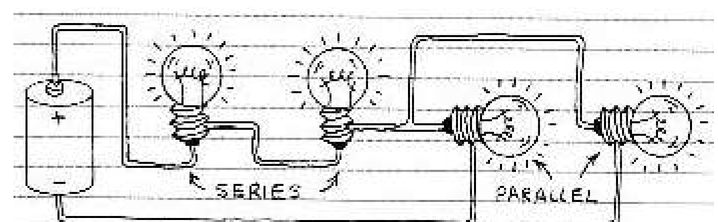
SERIES CIRCUIT
formed when current flowing through one component first flows through another.



PARALLEL CIRCUIT
when 2 or more components are connected so current can flow through one component without having to first flow through another.

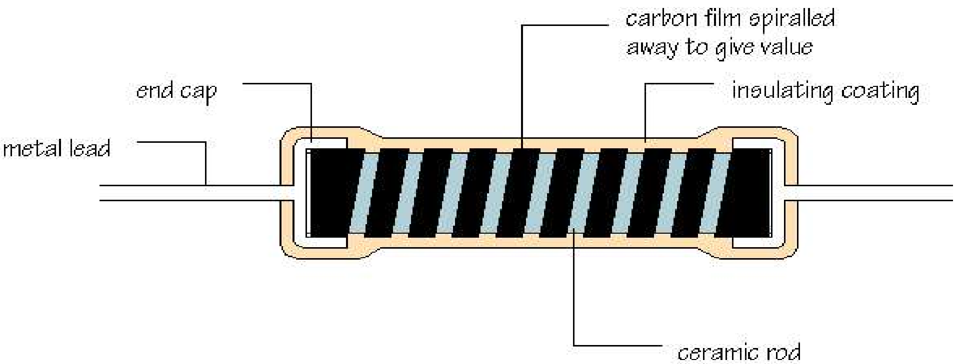


SERIES-PARALLEL CIRCUIT
Many circuits are combination circuits, all provide a complete path between the circuit and the power supply.



RESISTORS

Resistors limit current



Resistors in Series

$$r_s = r_1 + r_2 + r_3 \ldots$$

$$v_s = v_1 + v_2 + v_3 \ldots$$

$$I_s = I_1 = I_2 = I_3 \ldots$$

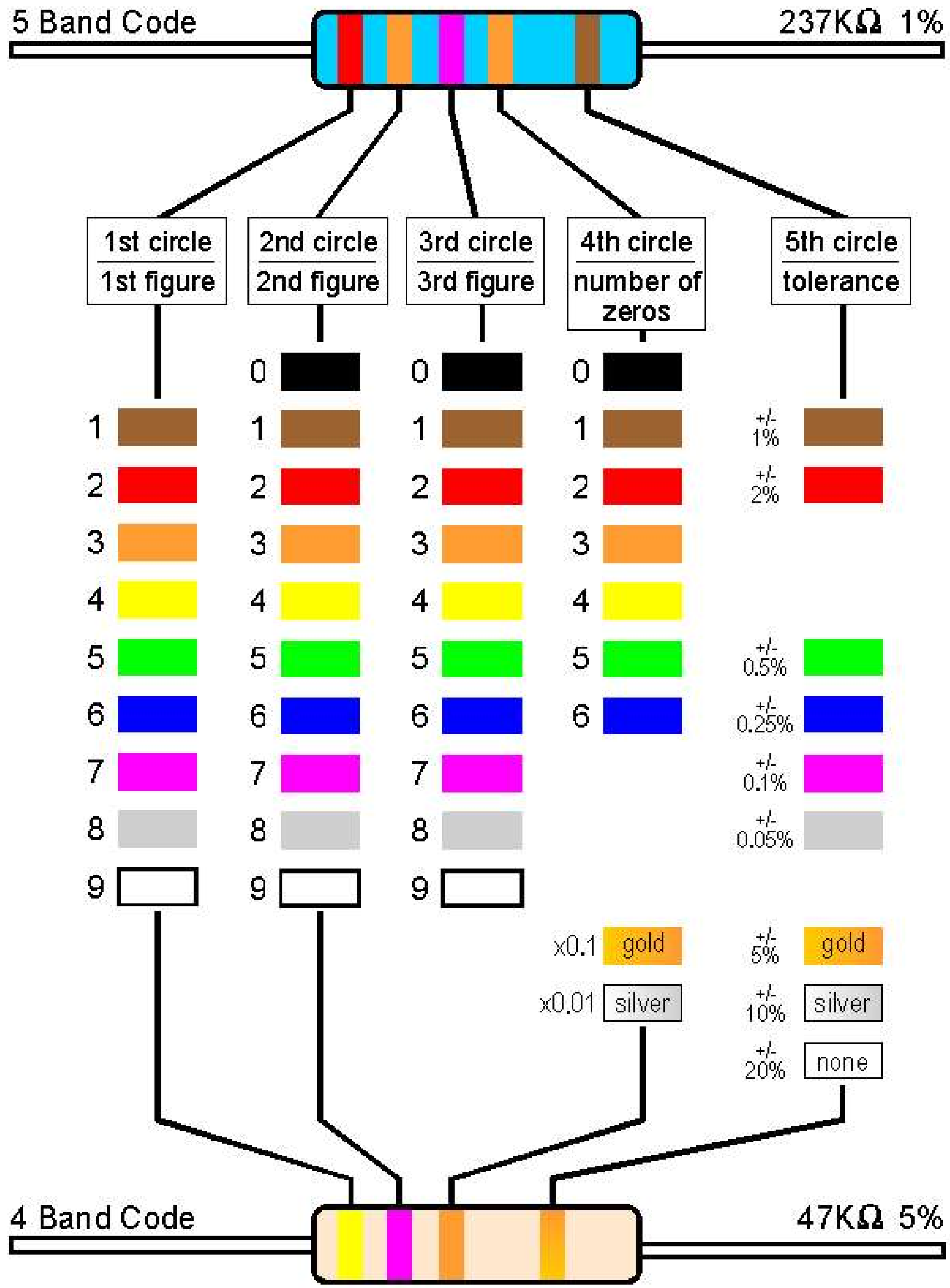
Resistors in Parallel

$$\frac{1}{r_p} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \ldots$$

$$v_p = v_1 = v_2 = v_3 \ldots$$

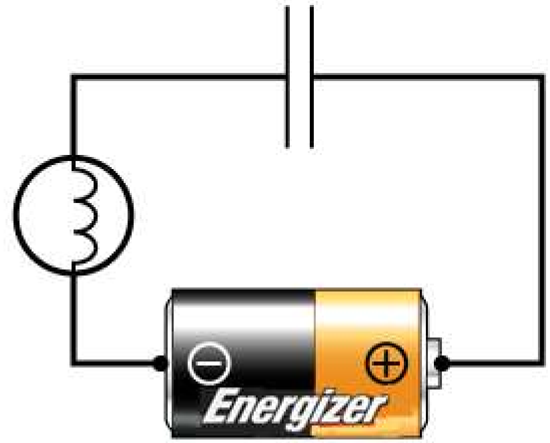
$$I_p = I_1 + I_2 + I_3 \ldots$$

Measured in OHMS Ω



CAPACITORS

Capacitors store electrical energy



Example: battery, light bulb and capacitor.
If the capacitor is pretty big, you would notice that when you connect the battery, the light bulb would light up as current flows from the battery to the capacitor to charge it up.

The bulb will get progressively dimmer and finally go out once the capacitor reaches its capacity.

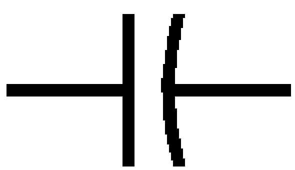
Then you can remove the battery and replace it with a wire. Current will flow from one plate of the capacitor to the other.
The light bulb will light and then get dimmer, finally going out once the capacitor completely discharges (same number of electrons on both plates).

Capacitors in Series

$$v_s = v_1 + v_2 + v_3 \ldots$$

$$\frac{1}{c_s} = \frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_3} \ldots$$

$$q_s = q_1 = q_2 = q_3 \ldots$$



Capacitors in Parallel

$$q_p = q_1 + q_2 + q_3 \ldots$$

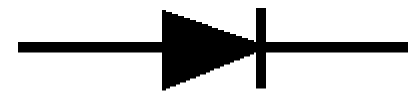
$$c_p = c_1 + c_2 + c_3 \ldots$$

$$v_p = v_1 = v_2 = v_3 \ldots$$

Measured in FARADS

DIODES (Rectifiers)

allow electrical current to flow through in only one direction and are used to convert alternating current into direct current.



Diodes will not conduct until forward voltage reaches a certain threshold.
If forward current exceeds diode capacity, damage will occur.
Excess reverse voltage will also damage diode.

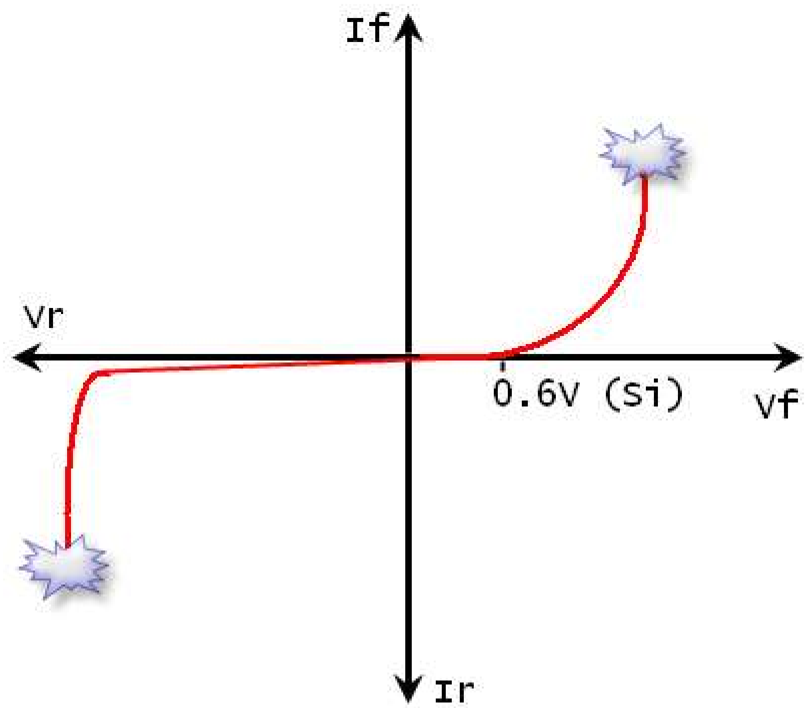
Small Signal Diodes:
Transform low current AC to DC

Power Rectifiers:
Identical to Signal diodes, but handle larger currents

Zener Diodes:
Designed to have specific reverse breakdown voltage, function like voltage sensitive switch

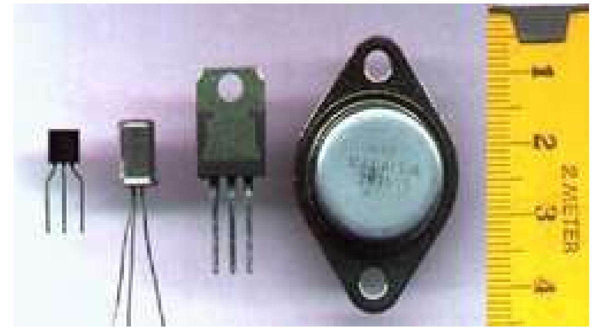
Light Emitting Diodes (LED):
Diodes made from certain semiconductors emit EM radiation when forward biased.

Photodiodes:
All diodes respond to some degree to illumination.Photodiodes are specifically designed to detect light.



Vr/Vf: reverse/forward voltage
Ir/ If : reverse/forward current
DIODE OPERATION SUMMARY

TRANSISTORS



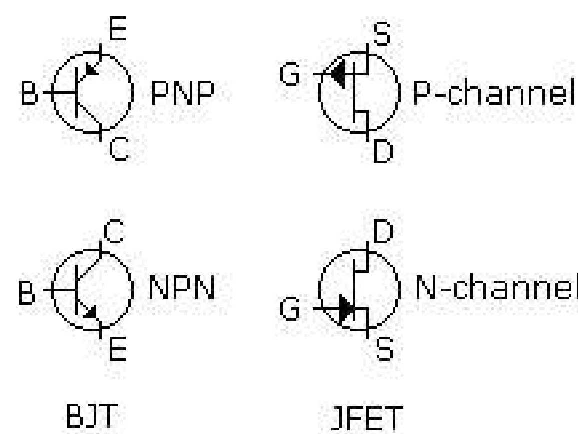
have two key properties:
1) they can amplify an electrical signal and
2) they can switch on and off, letting current through or blocking it as necessary.

Two main families of transistors:
BIPOLAR Junction Transistor: (BJT) consists of two sections of one type of semiconductor (N or P) around a middle slab of the other type. The junctions between the sections cause an incoming weak electrical signal to be amplified

FIELD EFFECT transistor (FET): incoming weak electrical signal create an electrical field across a section of semiconductor. This field causes a second electrical current to flow across the semiconductor, identical to the first weak signal, but stronger.
They act as a variable valve which, based on its input current (BJT) or input voltage (FET), allowing a precise amount of current to flow through it from the circuit's voltage supply

A transistor generally has three terminals:
BASE, EMITTER, COLLECTOR
A current or voltage applied through/across two terminals controls a larger current through the other terminal and the common terminal.

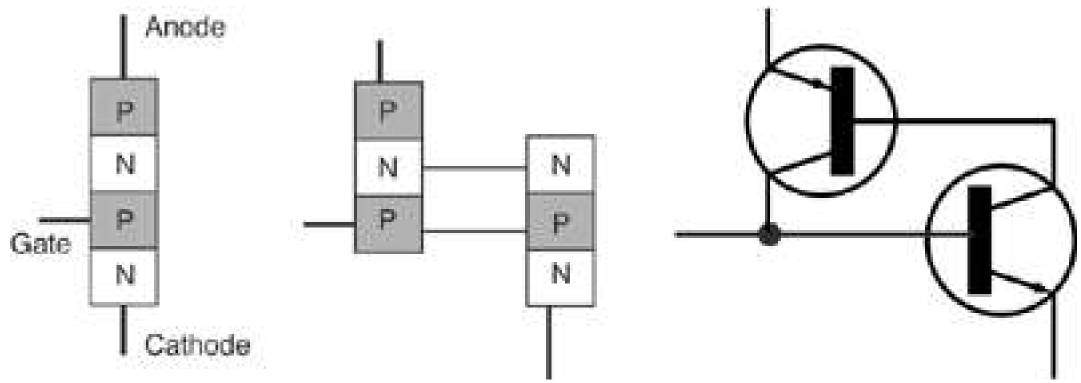
Base-Emitter junction will not conduct until forward voltage exceeds threshold (0.6V)
Excess current / voltage can damage transistors.



THYRISTORS

similar to diodes, with an extra terminal used to turn them on/off.
Do not amplify, they are just solid state switches.

Two families: Silicon Controlled Rectifiers (SCR) and TRIACs. SCRs switch direct current and TRIACs switch alternating current.
The operation of a SCR thyristor can be understood in terms of a pair of coupled transistors, arranged to cause the self-latching action.



TRIACs are equivalent to 2 SCRs connected in reverse parallel (with polarity reversed). This results in a bidirectional electronic switch which can conduct current in either direction when it is triggered (turned on).

It can be triggered by either a positive or a negative voltage being applied to its gate electrode.

Once triggered, the device continues to conduct until the current through it drops below a certain threshold value, such as at the end of a half-cycle of alternating current mains power.

SENSOR TYPES

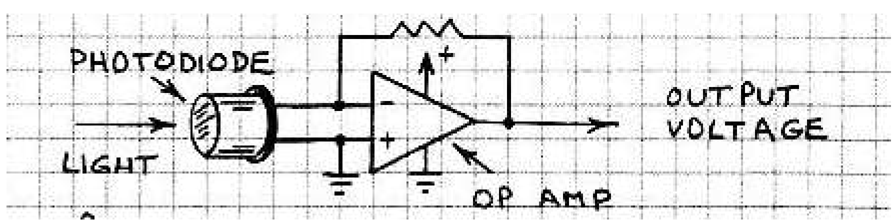
Most sensors can be placed in one of two categories:simple go/no-go sensors that act like binary on/off switches and analog sensors whose output is proportional to the stimulus.

Binary sensors include magnetic reed switches, pendulum and tripwire switches. Analog sensors include: photoresistors, photodiodes, thermistors, microphones and piezoelectric crystals.

OP AMPS

Sensors require a method of indicating when something has been sensed, such as an acoustic buzzer or lighting a warning light for simple binary sensors. Analog sensors can use analog or digital meters, an oscilloscope or a computer. Many analog sensors require a circuit to prepare the signal prior to output.

OpAmps (Operational Amplifier) are central to a variety of signal conditioning circuits which can be used with sensors.
For instance, they can be used to transform the tiny current from a photodiode into a voltage that is easily indicated by a meter.

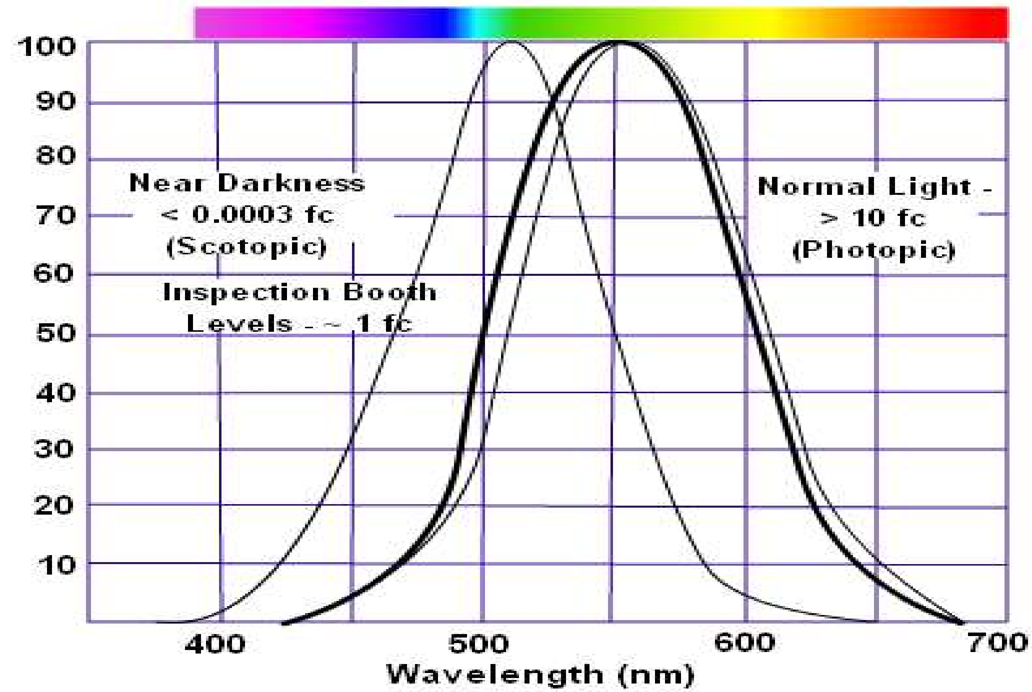


PHOTONIC SEMICONDUCTORS

Photonics is the field of electronics involving devices that emit and detect light.

The Ultraviolet, Visible and Infrared portions of the EM spectrum make up the OPTICAL SPECTUM

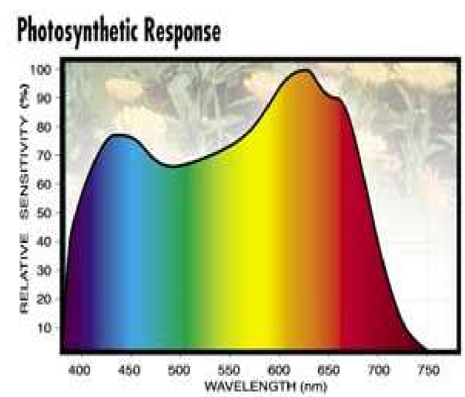
Human Eye Response to Light

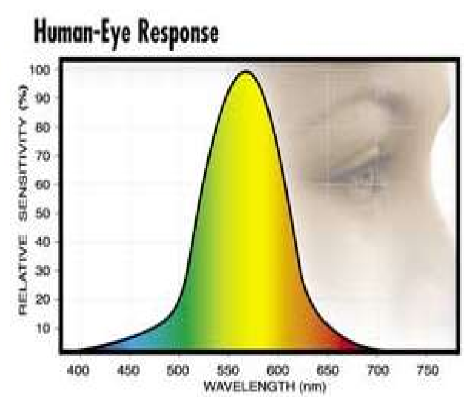


Normalized response of an average human eye to various amounts of ambient light. The shift in sensitivity occurs because two types of photoreceptors, cones and rods, are responsible for the eye's response to light. The curve on the right shows the eye's response under normal lighting conditions and this is called the photopic response

Many photonic semiconductors emit or detect near-infrared radiation. Silicon can detect visible light, but is most sensitive to near-infrared at 880 nm.

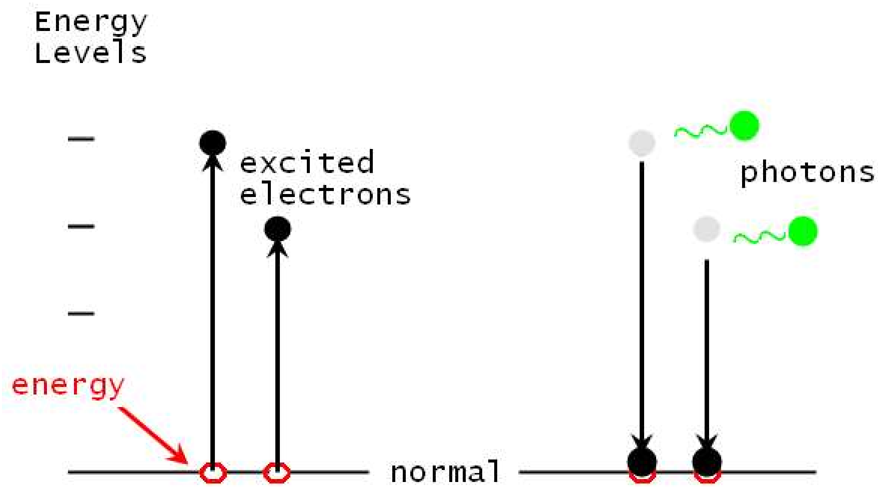
Because so many components can operate in both visible and near-IR, it is common to refer to near-infrared as light.





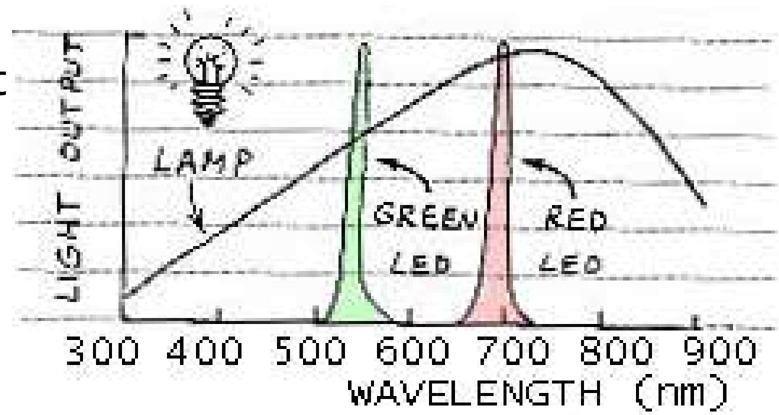
PHOTONS

"particles of light", produced when an electron that has been excited to a higher than normal energy level falls back to its normal level.



When bombarded by energy, (light, heat, electrons), most semiconductor crystals will emit visible or infrared light.

LEDs convert an electrical current directly into light and are more efficient than many other light sources



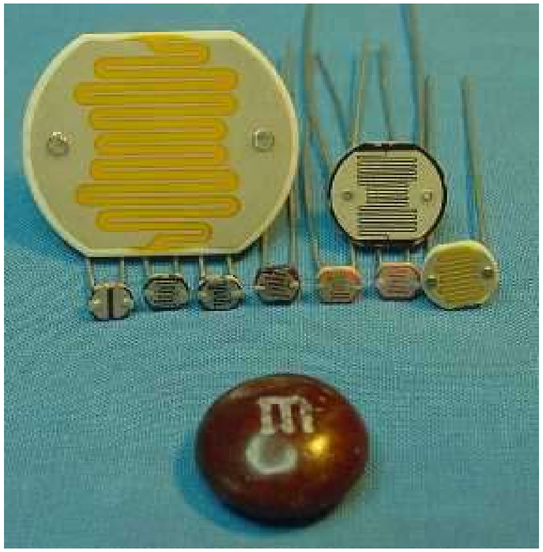
LEDs emit narrow wavelength range, because all electrons in LED are excited to same energy level. In comparison, an incandescent light emits over a broad wavelength range.

SEMICONDUCTOR LIGHT DETECTORS

Energy entering a semiconductor crystal excites electrons to higher levels, leaving behind holes. These electrons and holes can recombine and emit photons or they can move away from each other and form a current.

This is the basis of semiconductor light detectors.
There are 2 basic classes of detector, those without PN junctions (photoresistors) and those with PN junctions (photodiodes, phototransistors, photothyristors, solar cells).

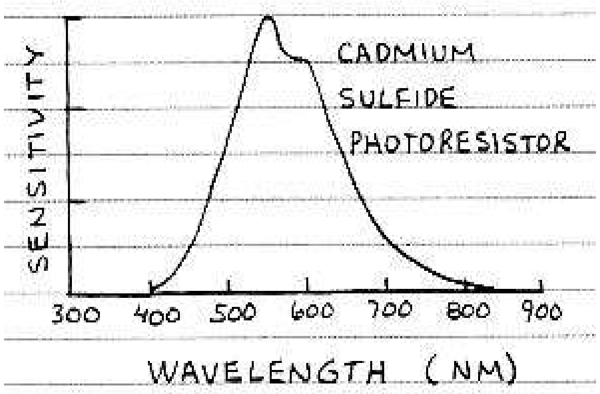
PHOTORESISTORS



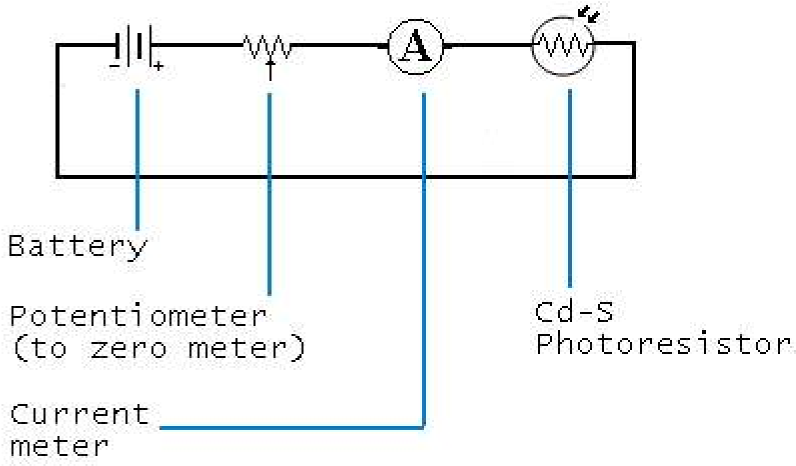
Photoresistors are semiconductor light detectors with no PN junction, whose resistance changes with light.

Their resistance is very high (millions of Ohms) when no light is present.
When illuminated, resistance is very low (hundreds of Ohms)

Photoresistors display a memory effect, they may require a second or more to return to their high resistance state after a light source is removed.



Cadmium Sulfide is most commonly used in photoresistors. CdS is primarily sensitive to green light, its sensitivity is very similar to that of the human eye.



PHOTODIODES

All PN Junctions are light sensitive.

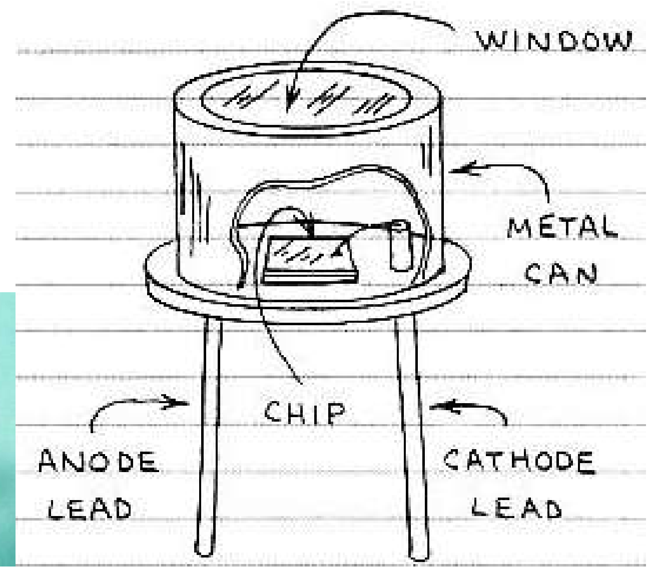
Photodiodes are PN Junctions specifically designed for light detection, which produce a current in response to light.

Two operating modes are possible:

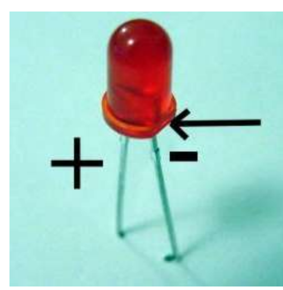
PHOTOVOLTAIC mode:
the photodiode becomes a current source when illuminated

PHOTOCONDUCTIVE mode:
the photodiode is reverse biased , current flows when the PN junction is illuminated. When dark, a tiny current called the dark current will flow.

Most PN Junction light detectors are made of Silicon, and can detect both visible and near-infrared. Photodiodes are commonly used to detect fast pulses of near-IR (lightwave communications).



LEDs can both emit AND detect light.



PHOTOTRANSISTORS

Like diodes, all transistors are light-sensitive. Phototransistors are designed to take advantage of this fact. The most-common variant is an NPN bipolar transistor with an exposed base region. Here, light striking the base replaces what would ordinarily be voltage applied to the base -- so, a phototransistor amplifies variations in the number of photons.

Note that phototransistors may or may not have a base lead (if they do, the base lead allows you to bias the phototransistor's light response.

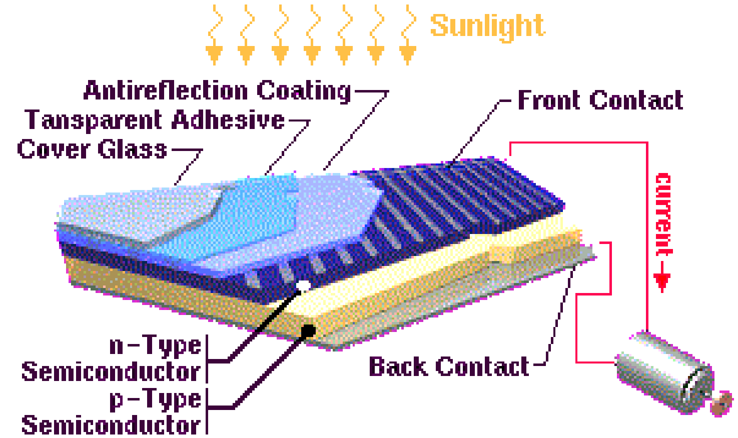
PHOTOTHYRISTORS

Photothyristors are various kinds of light-activated thyristors. You can think of them as light-activated switches. The most important member of the family is the light-activated silicon controlled rectifier, or LASCR. Light activated triacs are also made. Neither of the can switch as much current as conventional thyristors.

LASCRs -

To improve their sensitivity to light, the LASCR is made thinner than standard SCRs. This limits the amount of current they can switch. For high current applications, a LASCR can be used to trigger a regular SCR. LASCRs can switch up to a few hundred volts, but the maximum current is limited to a few tenths of an ampere.

SOLAR CELLS



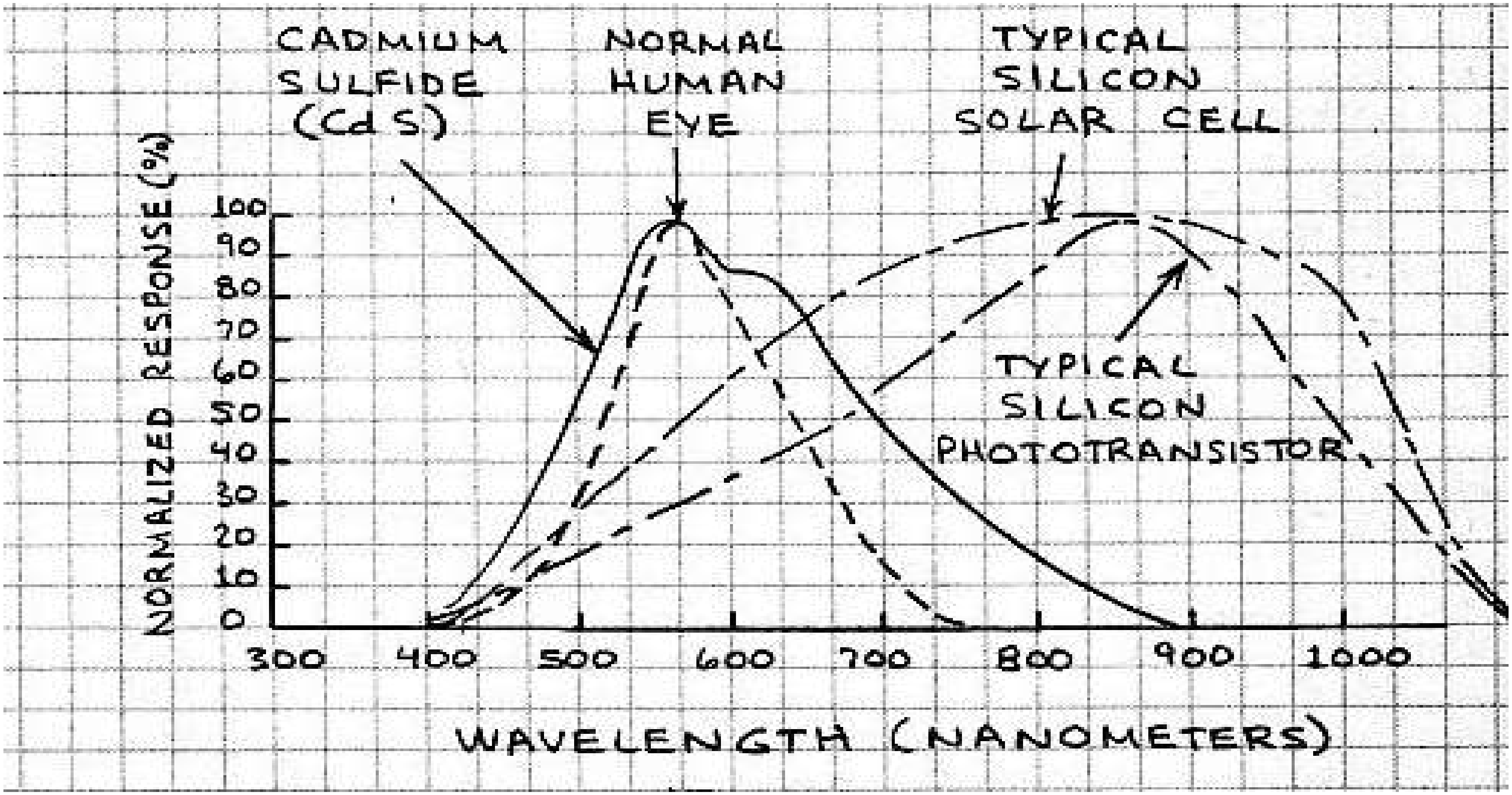
Solar cells are PN Junction photodiodes with a large light sensitive area.
A single silicon solar cell can generate 0.5V in bright sunlight.

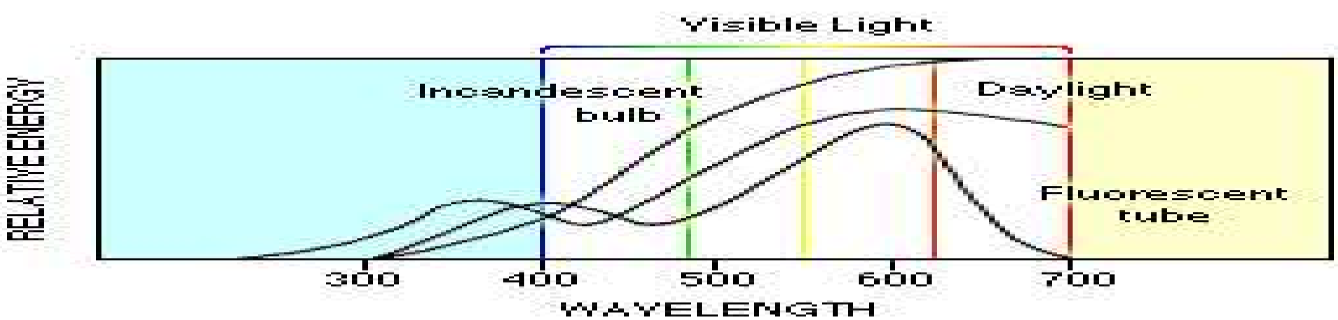
Many different kinds and shapes of solar cells are made. They are often connected in series or parallel.

If connected in series, the output voltage is the sum of voltages of each cell.
When in parallel, the output current is the sum of currents of each solar cell.
Arrays of solar cells can charge rechargeable cells and batteries.

Solar cells can also be used as detectors of visible and near-IR light.
A typical solar cell responds to changes in light intensity within 20 microseconds,so they can be used to detect voice modulated lightwave signals.

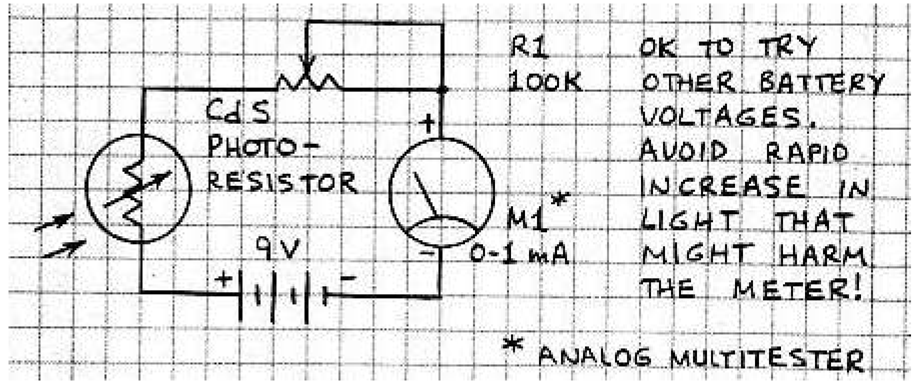
PHOTOSENSORS SPECTRAL RESPONSE



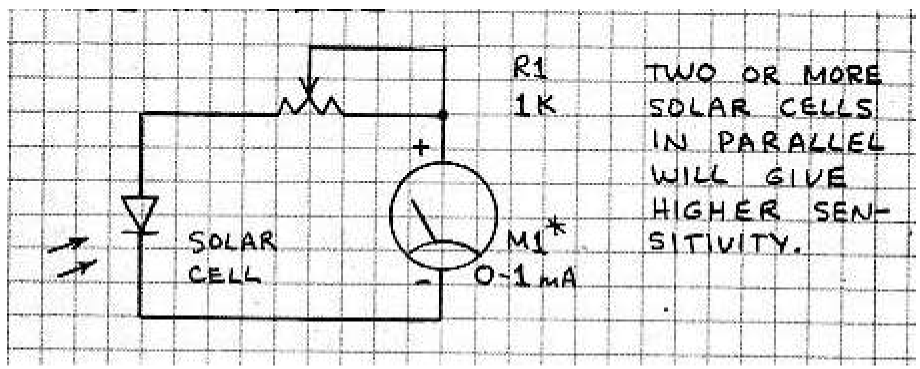


SIMPLE LIGHT METERS

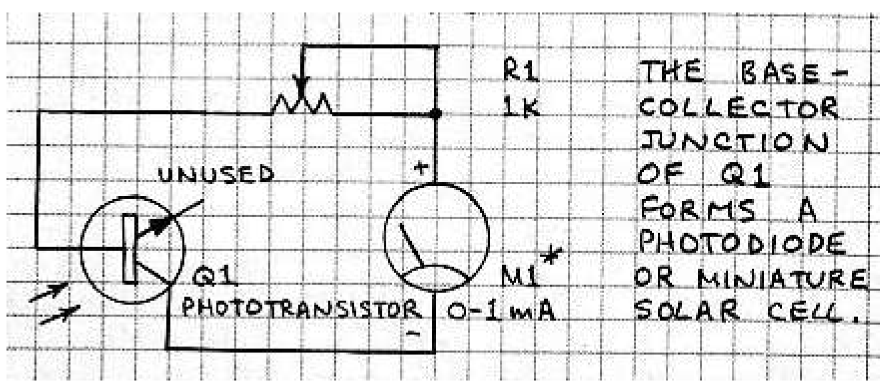
PHOTORESISTOR



SOLAR CELL

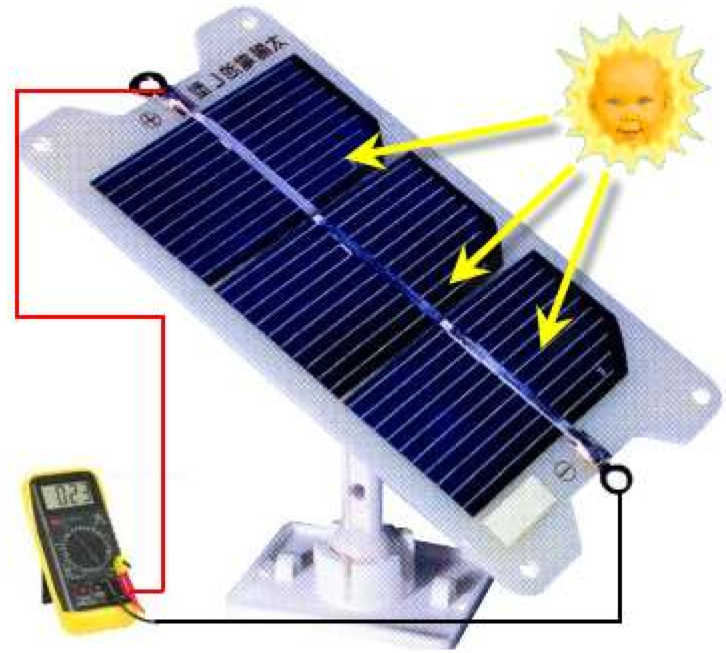


PHOTOTRANSISTOR

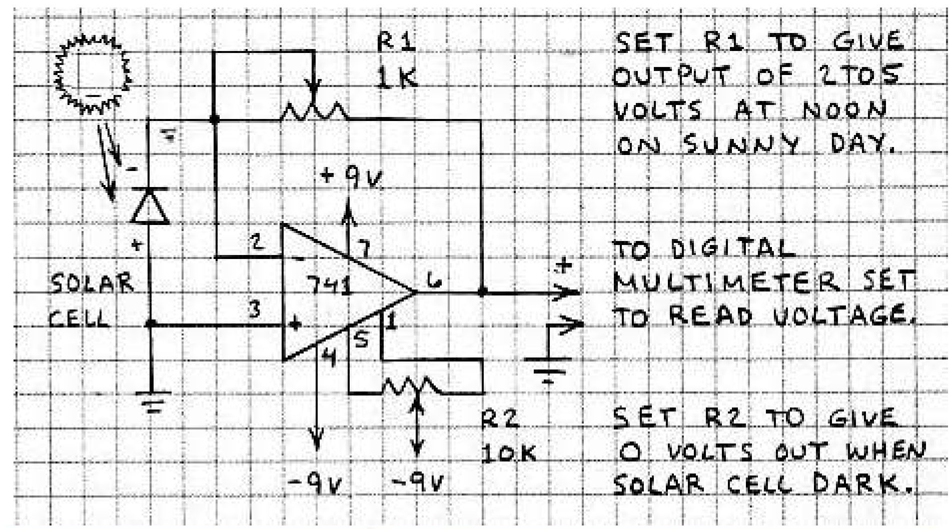


SIMPLE SOLAR POWER METER

Solar power at the Earth's surface is influenced by atmospheric conditions and the sun's angle.
A simple solar power meter can be made by connecting a solar cell with a multimeter set to read current (ammeter mode).
The current from the cell represents the sunlight intensity over the solar cell's spectral response.

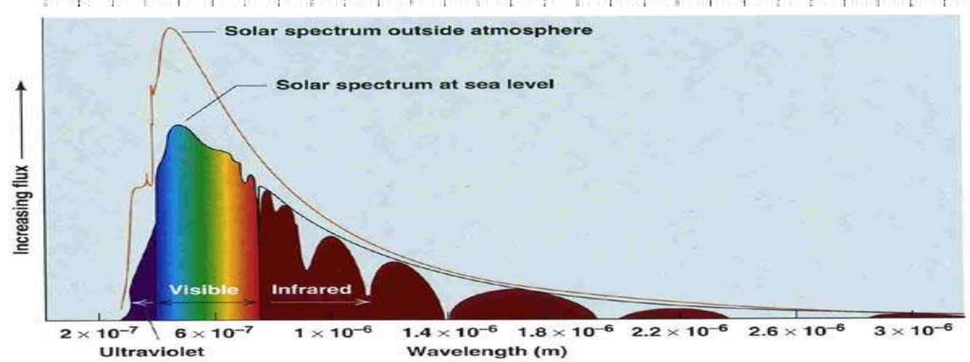


OPAMP SOLAR POWER METER



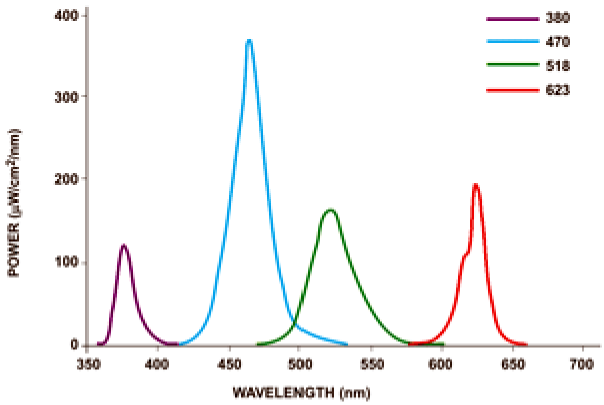
Use an LS741 OpAmp to convert the current from the solar cell into voltages.
Use potentiometers to adjust voltage range for full/zero light conditions.

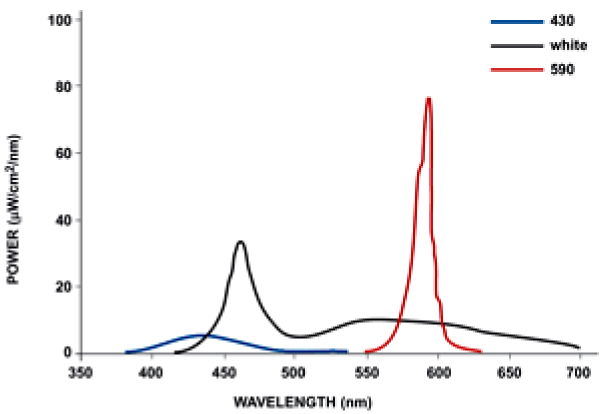
Monitoring solar power is an easy way to learn about the atmosphere and power absorption characteristics of different cloud cover / air pollution.



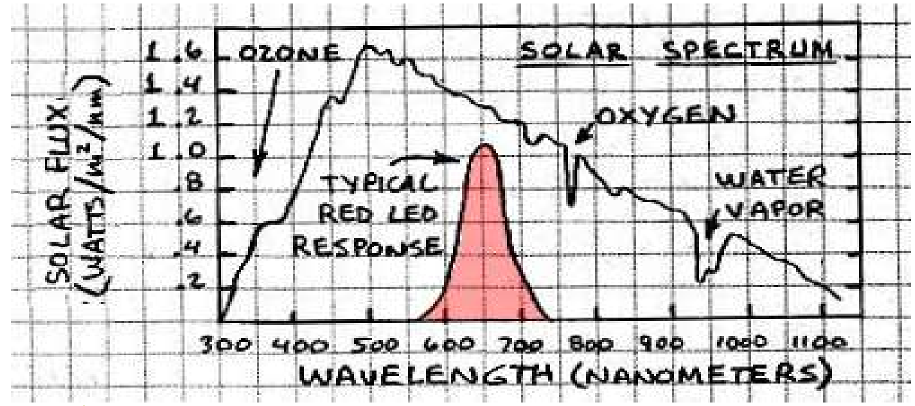
LED SUN PHOTOMETER

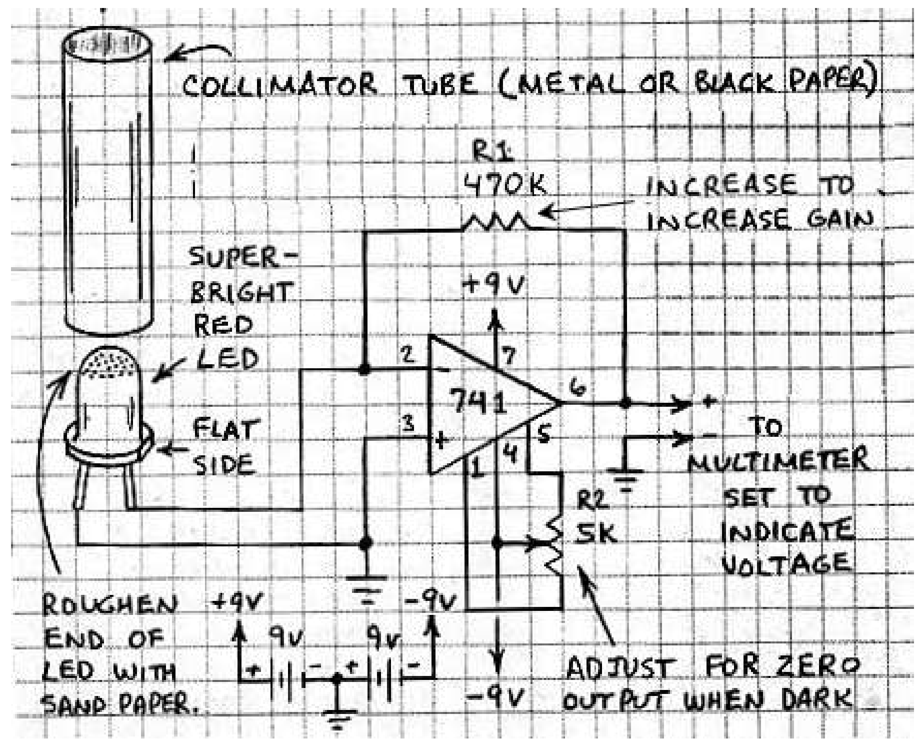
LEDs emit and detect light over a narrow band of wavelengths (30-150nm).
This means an LED can be used in a sun photometer without an external optical filter.





Spectral responses of LEDs

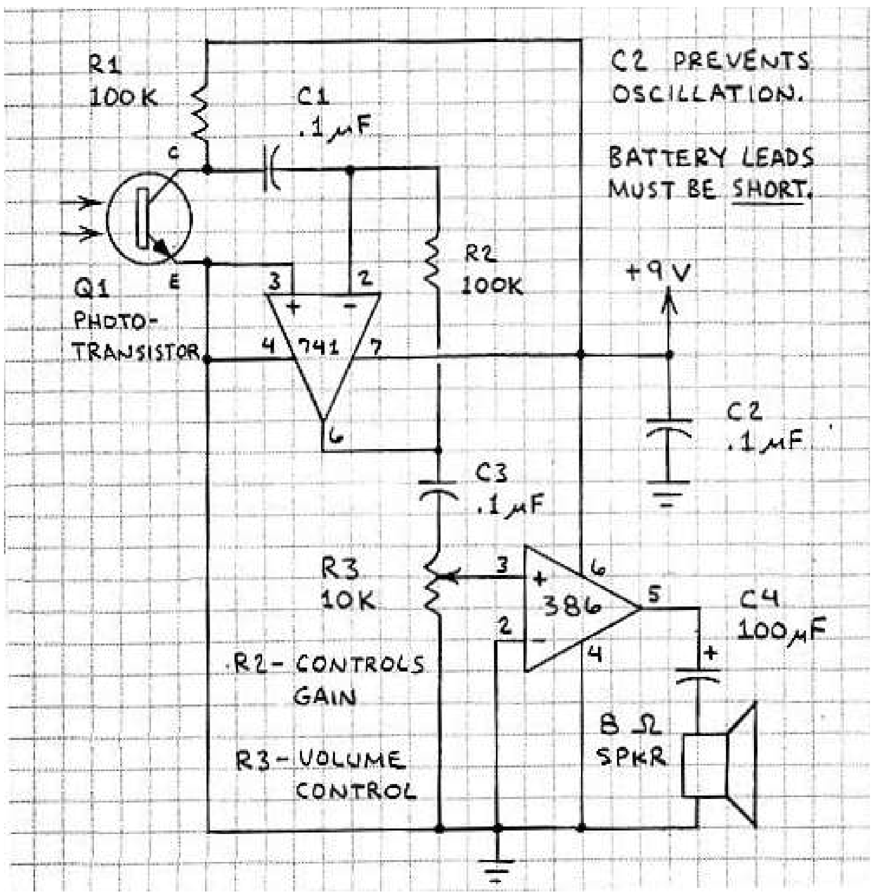




Mims F.M. (1992) Sun Photometer with LEDs
Applied Optics,31(33):6965-6967

LIGHT LISTENER

Human eye persistence of vision of ~0.02 seconds, so any light flickering more than about 50Hz appears to be continuously on.
Light-listener circuit transforms the flickering of light that the eye cannot discern into sounds that are easier to perceive.
The human range of hearing is between 20-20,000 Hz



SEEING WITH SOUND

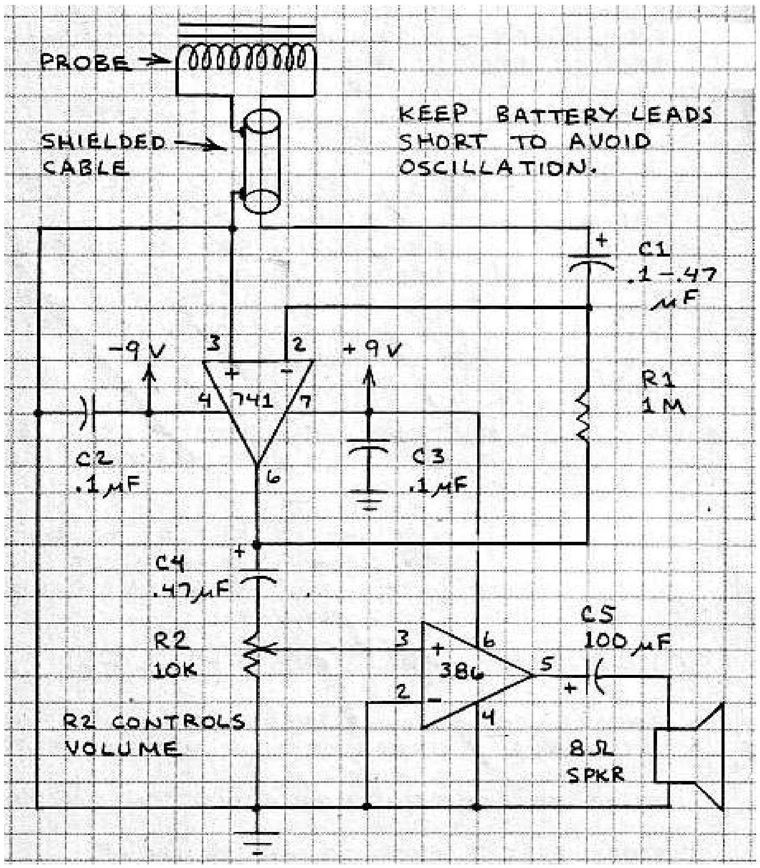
The vOICe vision technology for the totally blind offers the experience of live camera views through sophisticated image-to-sound renderings.
The ultimate goal is to provide synthetic vision with truly visual sensations by exploiting the neural plasticity of the human brain.
Neuroscience research has already shown that the visual cortex of even adult blind people can become responsive to sound, and The vOICe technology may now reinforce this in a visual sense with live video from a head-mounted camera encoded in sound.
The vOICe vision technology is being explored and developed under the Open Innovation paradigm together with R&D partners around the world.

http://www.seeingwithsound.com/voice.htm

ELECTROMAGNETIC PROBE

This circuit converts pulsing electromagnetic fields into sound.
Telephone pickup coil used as probe.

Small magnetic pickup coil that has an attached suction cup.
attached to the phone earpiece and picks up both sides of conversation.



Test the probe by placing near a telephone receiver. Should hear dial tone when phone is off the hook.

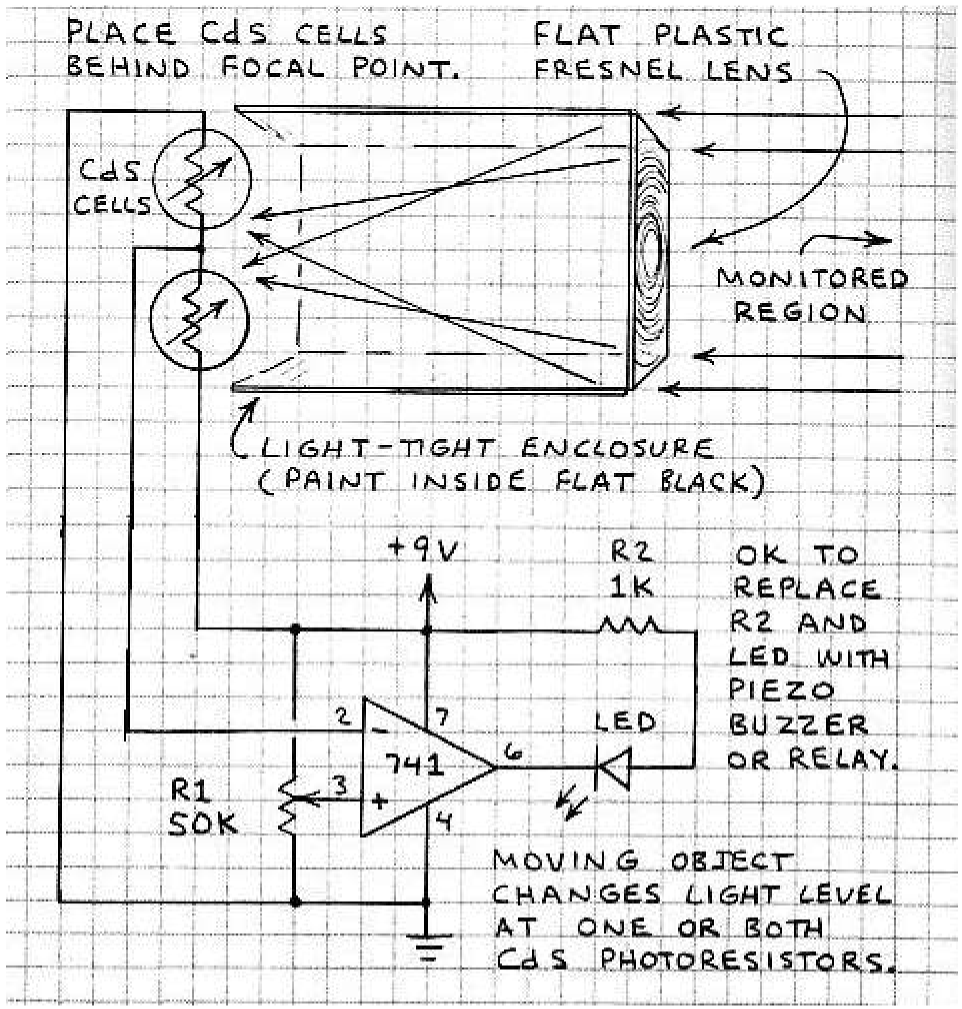
Circuit can be used to find AC carrying wires in walls.

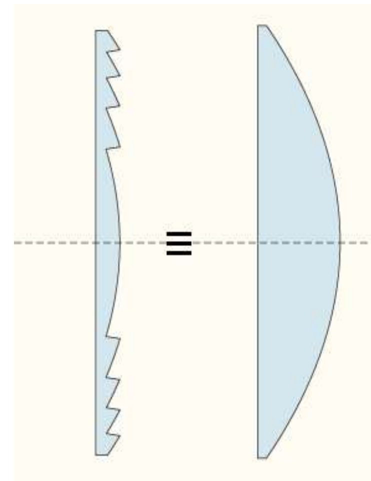
All EM generating equipment can be tested and differentiated using acoustic signatures.

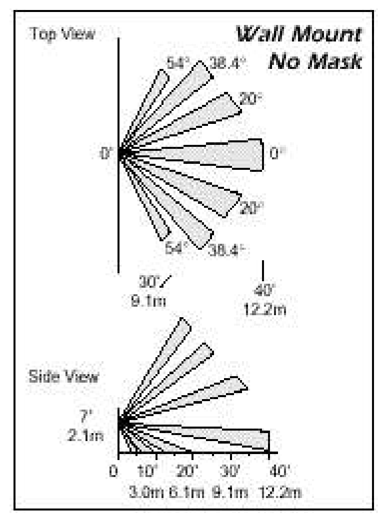
MOTION SENSOR

When adjusted properly, this circuit will detect movement of an object within its field of view. Detection range can be 10's of feet.

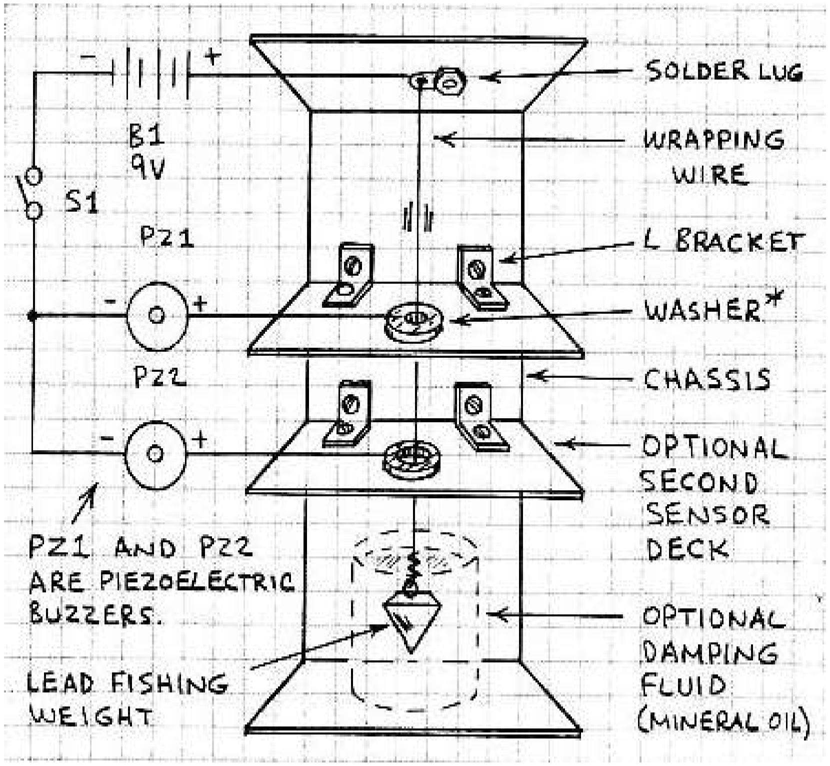
Use a flat magnifying Fresnel lens at least 6 inches square. Point lens at area to be monitored. Adjust R1 until LED just switches off. Moving object will light LED.

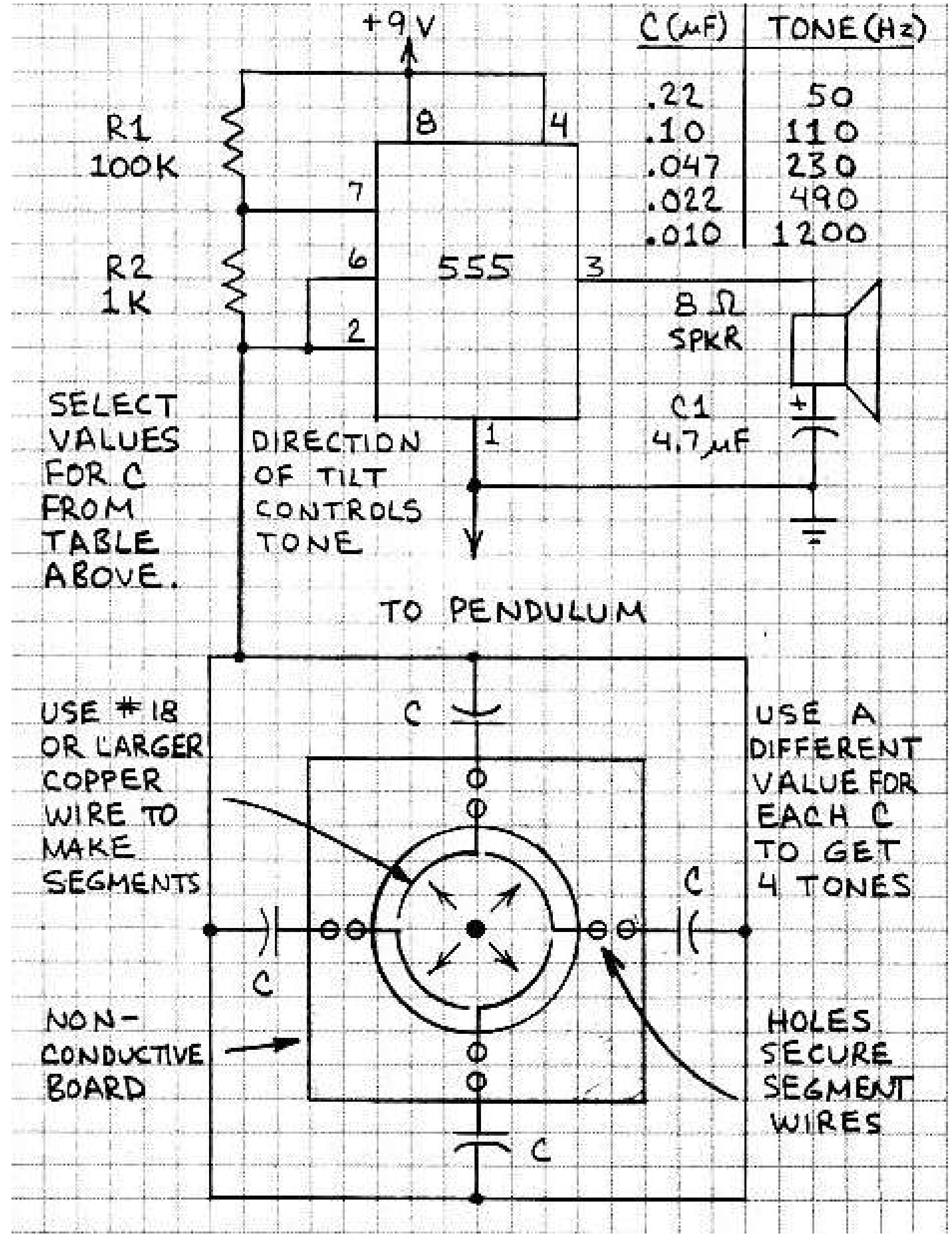






PENDULUM SWITCH





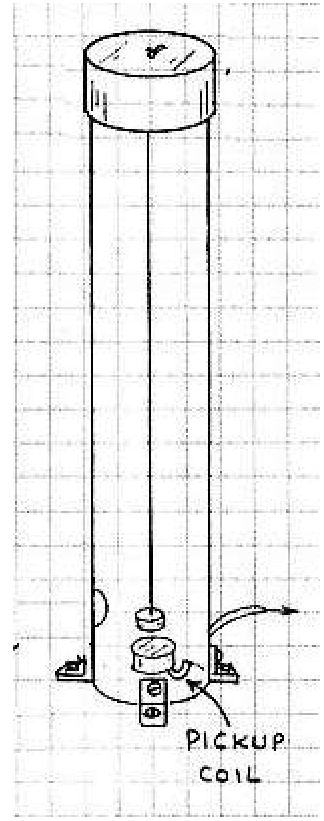
Pendulum switches detect tilt/vibration. Above circuit is simple binary switch, or replacing the sensor ring (washer) with a circular array of four or more segments allows for determination of the direction of tilt or vibration, seen in pendulum quadrant switch circuit to the right.

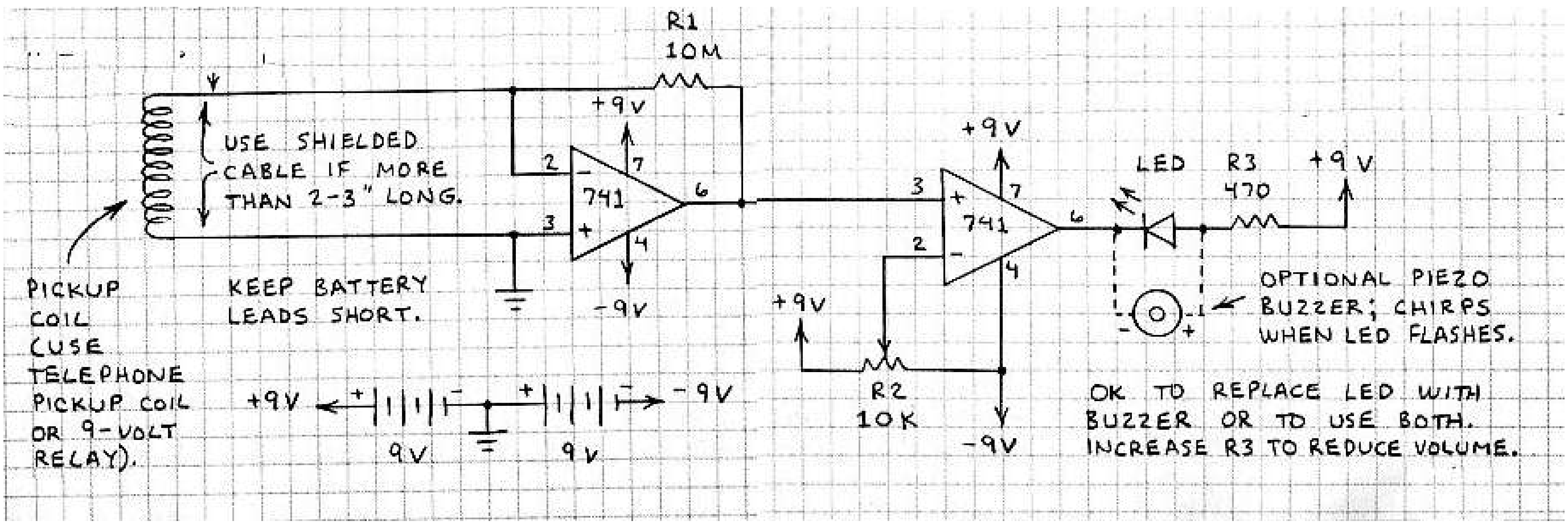
SEISMIC MOVEMENT SENSOR

Exceedingly sensitive sensor, using a magnet as a pendulum above a pickup coil. If LED doesn't stop flickering, reduce the sensitivity (R2) or increase the air gap between the magnet and the pickup coil.

Mount the magnet in a windproof plastic pipe and bolt to a sturdy foundation for best results.

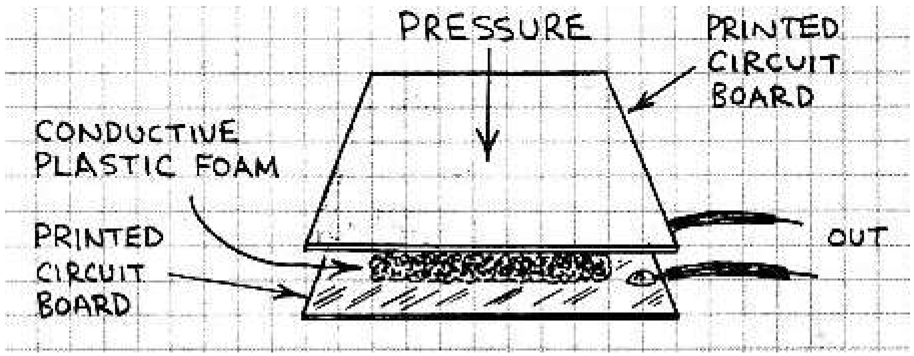
Circuit is said to have detected trains on tracks over a mile away from sensor, and Nevada underground nuclear tests from test site in Texas.



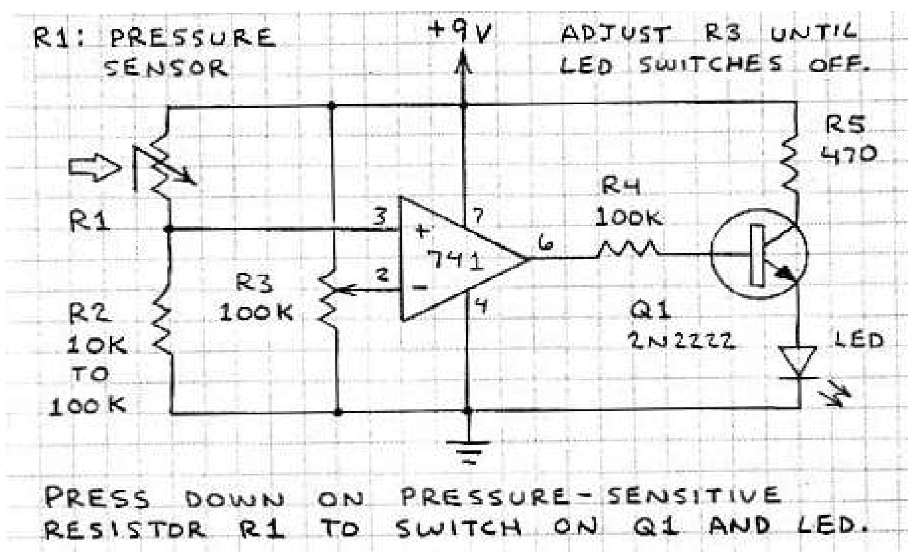


SIMPLE PRESSURE SENSOR

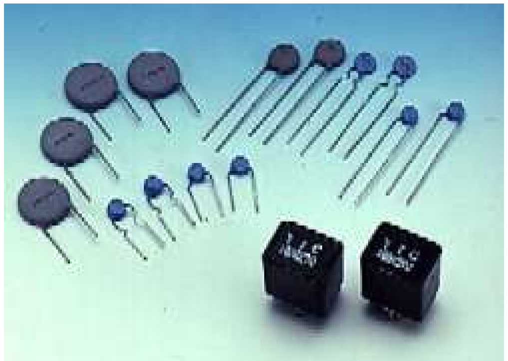
Inaccurate but easy to manufacture pressure sensors use conductive copper plates (or pennies) to sandwich conductive plastic foam or conductive plastic sheet.
Conductive foam can be found protecting static sensitive devices (IC's).



PRESSURE SENSITIVE SWITCH



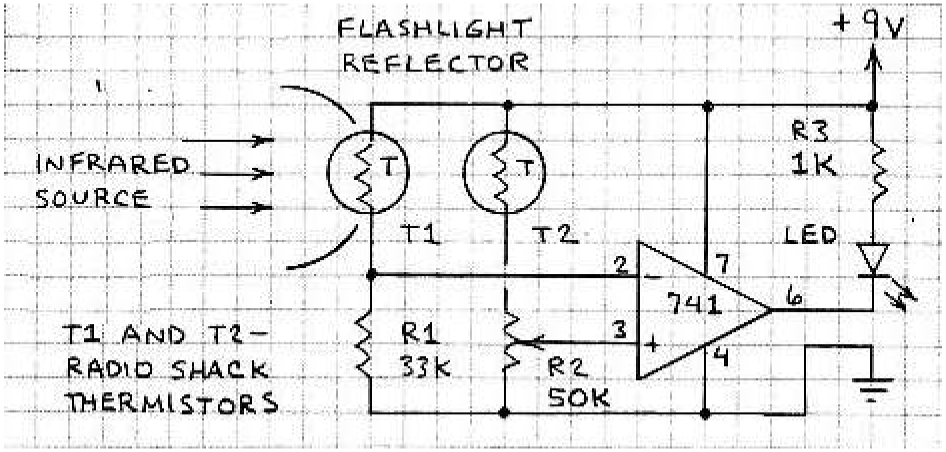
THERMISTOR



Thermistors are temperature dependent resistors, whose resistance decreases as temperature increases. They have high accuracy but are limited in their temperature range.

A thermistor installed at the focal point of a flashlight reflector can be used to detect infrared radiation from heat sources.

INFRARED SWITCH

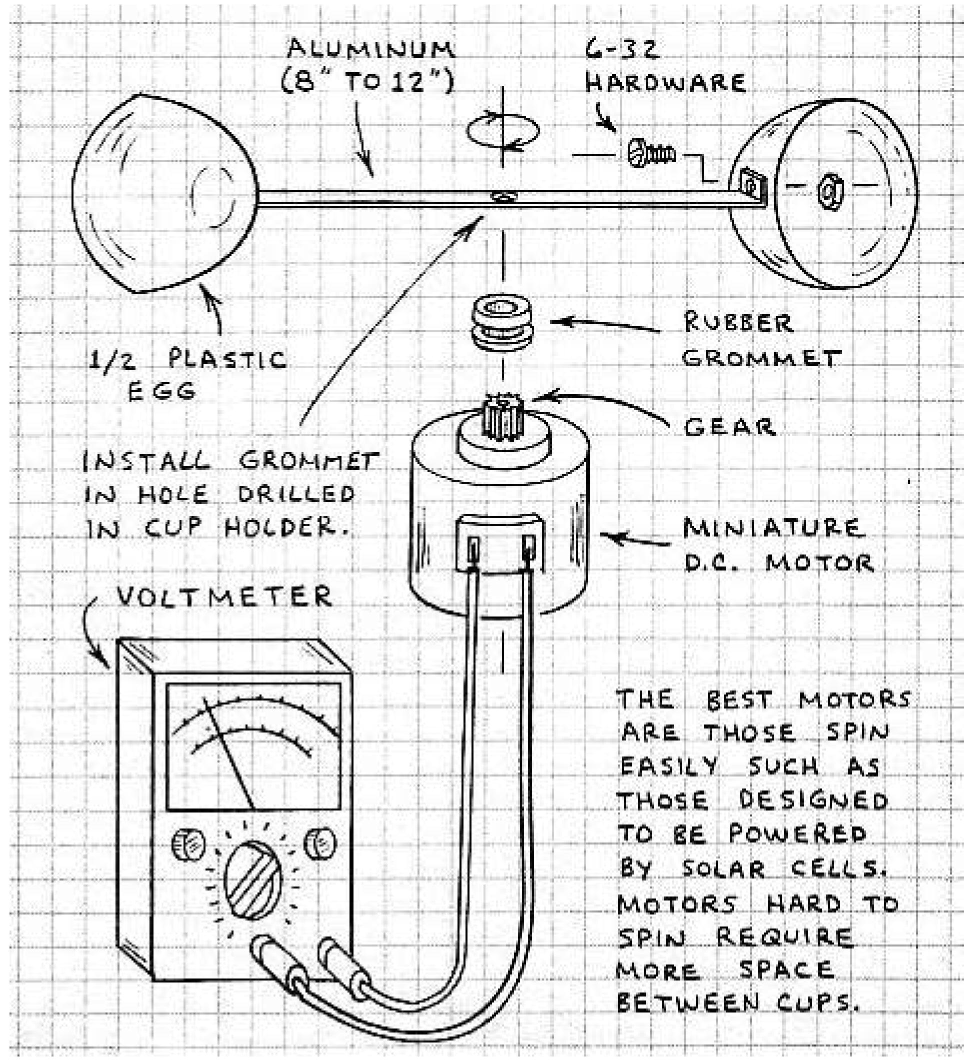


Power circuit and wait a few seconds for thermistors to stabilize, then adjust R2 until LED just switches off. Placing hand near reflector should trigger circuit, a lit match will trigger it from about 3 feet or more.
Changes in air temperature cause equal changes in T1 and T2, but an infrared source will only affect T1.

WIND SPEED INDICATOR

Small DC motors will generate a voltage when the armature is spun. This can be used to make a simple wind speed indicator.

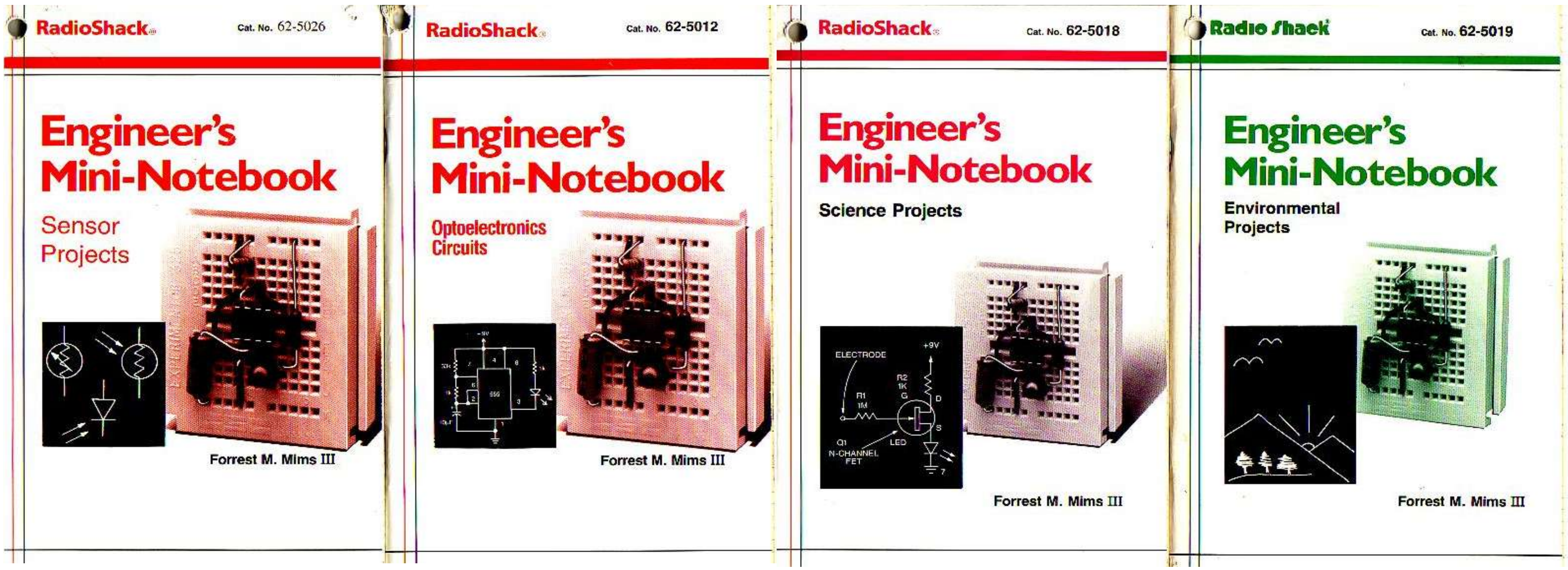
Calibration can be accomplished by direct comparison with a commercial anemometer or by graphing output voltages produced whilst holding the unit out the window of a moving vehicle.



COMPONENT	SYMBOL								
Ammeter	A	Diode,General		Jack,coaxial		Rectifier, Semiconductor		Transformer, Iron-Core	
AND gate		Diode,Gunn		Jack,Phone 2 conductor		Rectifier, Silicon-Controlled		Transformer, Tapped Primary	
Antenna, Balanced		Diode,Light Emitting		Jack,Phone interupting		Rectifier Tube-Type		Transformer, Tapped Secondary	
Antenna, General		Diode,Photosensitive		Jack,Phone 3 conductor		Relay,DPDT		Transistor, Bipolar NPN	
Antenna Loop, Shielded		Diode,Photovoltaic		Jack,Phono		Relay,DPST		Transistor, Bipolar PNP	
Antenna Loop, Unshielded		Diode,Pin		Key,Telegraph		Relay,SPDT		Transistor,N Channel Field Effect	
Antenna, Unbalanced		Diode,Varactor		Lamp,Incandescent		Relay,SPST		Transistor,P channel Field Effect	
Attenuator, Fixed		Diode,Zener		Lamp,Neon		Resistor		Transistor,Dual Gate Metal Oxide	
Attenuator, Variable		Directional Coupler		Male Contact, General		Resonator		Transistor,Single Gate Metal Oxide	
Battery		EXCLUSIVE-OR gate		Microphone		Rheostat		Transistor, Photosensitive	
Capacitor, Feedthrough		Female Contact, General		NAND gate		Saturable Reactor		Transistor, Unijunction	
Capacitor,Fixed Nonpolarized		Ferrite Bead		Negative Voltage Connection		Shielding		Tube,Diode	
Capacitor,Fixed Polarized		Fuse		NOR gate		Signal Generator		Tube,Pentode	
Capacitor,Ganged Variable		Galvanometer	G	Op Amp		Speaker		Tube,Photomultiplier	
Capacitor,General		Ground,Chassis		OR gate		Switch DPDT		Tube,Tetrode	
Capacitor,Variable Single		Ground,Earth		Outlet Utility 110V		Switch DPST		Tube,Triode	
Capacitor,Variable Split-Stator		Handset		Outlet Utility 220V		Switch Momentary Contact		Unspecified Component	
Cathode,Cold		Headphone,Double		Photocell,Tube		Switch,Rotary		Voltmeter	V
Cathode, Directly Heated		Headphone,Single		Plug,Phone 2 conductor		Switch SPDT		Wattmeter	W
Cathode, Indirectly Heated		Inductor,Air-Core		Plug,Phone 3 conductor		Switch SPST		Wires	
Cavity Resonator		Inductor,Bifilar		Plug,Phono		Terminals,General Balanced		Wires, Connected	
Cell		Inductor,Iron-Core		Plug Utility 110V		Terminals,General Unbalanced		Wires, Not Connected	
Circuit Breaker		Inductor,Tapped		Plug Utility 220V		Test Point			
Coaxial Cable		Inductor,Variable		Positive Voltage Connection		Thermocouple			
Crystal, Piezoelectric		Integrated Circuit		Potentiometer		Thyristor			
Delay Line		Inverter		Probe, Radio-Frequency		Transformer, Air-Core			

EXTRA READING / REFERENCE

Circuits in these notes were obtained from the Engineer's Mini-Notebooks by Forrest Mims III (IEEE,NSTA)



RadioShack Cat.No.	Engineer's Mini-Notebooks
62-5026	Sensor Projects
62-5012	Optoelectronics Circuits
62-5018	Science Projects
62-5019	Environmental Projects