

TABLE OF CONTENTS

ANGSTROM

ANODE

BREWSTER'S ANGLE

CATHODE

CONTRAST RATIO

DEIONIZED WATER

DIODE

ELECTROMAGNETIC RADIATION

ELECTRONS

IONS

JFETS

JOULE

LASER

NEUTRONS

PELTIER EFFECT

PHASE VELOCITY

PHOTON

PIN DIODE

PLASMA

POLARIZER

PROTONS

RAD

RADIATION

X-RAYS, ALPHA PARTICLES, BETA PARTICLES, RADIATION EXPOSURE TABLE

REFRACTIVE INDEX

REM

SCALE

EXPONENTS, PREFIX, SCALE, DECIMAL EQUIVALENT

SIEVERT

SPUTTERING

TEC (PELTIER COOLER)

TEMPERATURE CONVERSIONS

THERMOELECTRIC EFFECT

TORR

VACUUM PRINCIPLES

MFP, OUTGASSING, CRYOPUMPS, REGENERATION

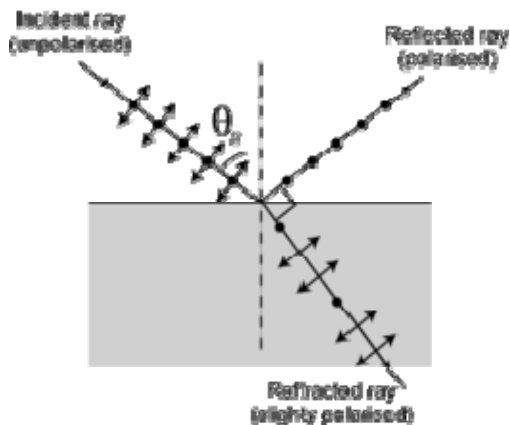
WAVELENGTH

GENERAL REFERNECE TERMS

ANGSTROM: 1 ångström (Å) = 1.0×10^{-10} meters = 0.1 nm = 100 picometers

ANODE: An anode is an electrode through which electric current flows *into* a polarized electrical device.

BREWSTER'S ANGLE: Brewster's angle (also known as the polarization angle) is an optical phenomenon named after the Scottish physicist, Sir David Brewster. When light moves between two media of differing refractive index, generally some of it is reflected at the boundary. At one particular angle of incidence, however, light with one particular polarization cannot be reflected. This angle of incidence is Brewster's angle, θ_B . The polarization that cannot be reflected at this angle is the one for which the electric field of the light waves lies in the same plane as the incident ray and the surface normal. Light with this polarization is said to be *p-polarized*, because it is parallel to the plane. Light with the perpendicular polarization is said to be *s-polarized*, from the German *senkrecht*—perpendicular. When unpolarized light strikes a surface at Brewster's angle, the reflected light is always *s-polarized*.



CATHODE: A cathode is an electrode through which electric current flows *out of* a polarized electrical device.

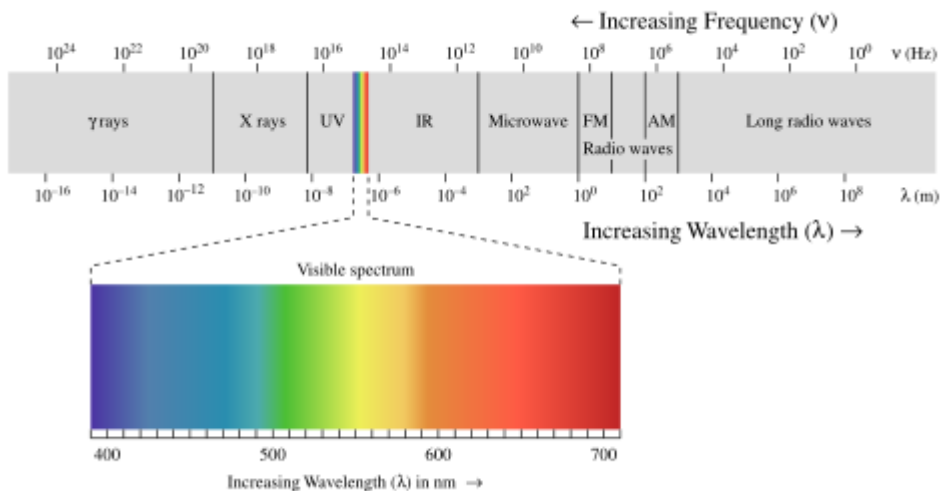
CONTRAST RATIO: A display system defined as the ratio of the luminosity of the brightest and the darkest color a system is capable of producing.

DEIONIZED WATER: Water that lacks ions; such as cations from sodium, calcium, iron, copper, and anions such as chloride and bromide. This means it has been purified from all other ions except H_3O^+ and OH^- , but it may still contain other non-ionic types of impurities such as organic compounds. The lack of ions causes the water's resistivity to increase.

DIODE: In electronics, a diode is a component that restricts the direction of movement of charge carriers. Basically, it allows an electric current to flow in one direction, but blocks it in the opposite direction. Thus, the diode can be thought of as an electronic version of a check valve. Circuits that require current flow in only one direction will typically include one or more diodes in the circuit design.

ELECTROMAGNETIC RADIATION: Electromagnetic [radiation](#) is a self-propagating wave in space with electric and magnetic components. These components oscillate at right angles to each other and to the direction of propagation, and are in phase with each other. Electromagnetic radiation is classified into types according to the frequency of the wave: these types include, in order of increasing frequency, radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, [X-rays](#) and gamma rays. EM radiation carries energy and momentum, which may be imparted when it interacts with matter. **Interference** is the superposition of two or more waves resulting in a new wave pattern. If the fields have components in the same direction, they **constructively interfere**, while opposite directions cause **destructive interference**.

Electromagnetic spectrum



Electromagnetic spectrum with light highlighted

CLASS	FREQUENCY	WAVELENGTH	ENERGY
γ	300 EHz	1 pm	1.24 MeV
HX	30 EHz	10 pm	124 keV
SX	3 EHz	100 pm	12.4 keV
	300 PHz	1 nm	1.24 keV
EUV	30 PHz	10 nm	124 eV
NUV	3 PHz	100 nm	12.4 eV
	300 THz	1 μ m	1.24 eV
NIR	30 THz	10 μ m	124 meV
MIR	3 THz	100 μ m	12.4 meV
FIR	300 GHz	1 mm	1.24 meV
EHF	30 GHz	1 cm	124 μ eV
SHF	3 GHz	1 dm	12.4 μ eV
UHF	300 MHz	1 m	1.24 μ eV
VHF	30 MHz	1 dam	124 neV
HF	3 MHz	1 hm	12.4 neV
MF	300 kHz	1 km	1.24 neV
LF	30 kHz	10 km	124 peV
VLF	3 kHz	100 km	12.4 peV
VF	300 Hz	1 Mm	1.24 peV
ELF	30 Hz	10 Mm	124 feV

Legend:

γ = Gamma rays

HX = Hard [X-rays](#)

SX = Soft X-Rays

EUV = Extreme ultraviolet

NUV = Near ultraviolet

Visible light

NIR = Near infrared

MIR = Moderate infrared

FIR = Far infrared

Radio waves:

EHF = Extremely high frequency (Microwaves)

SHF = Super high frequency (Microwaves)

UHF = Ultrahigh frequency

VHF = Very high frequency

HF = High frequency

MF = Medium frequency

LF = Low frequency

VLF = Very low frequency

VF = Voice frequency

ELF = Extremely low frequency

EM radiation with a wavelength between approximately 400 nm and 750 nm is detected by the human eye and perceived as visible light.

ELECTRONS: Electrons are subatomic particles which have a negative charge, and a size which is so small as to be almost unmeasurable, and which are the least heavy of the three principal components of an atom.

ION: An ion is an atom or group of atoms that normally are electrically neutral and achieve their status as an ion by loss or addition of one or more [electrons](#). The simplest ions are the [proton](#) (a hydrogen ion, H^+ , positive charge), and alpha particle (helium ion, He^{2+} , consisting of two protons and two [neutrons](#)). A negatively charged ion, which has more electrons in its electron shells than it has protons in its nuclei, is known as an **anion** due to its attraction to [anodes](#). A positively-charged ion, which has fewer electrons than protons, is known as a **cation** due to its attraction to [cathodes](#). Ions are denoted in the same way as electrically neutral atoms and molecules except for the presence of a superscript indicating the sign of the net electric charge and the number of electrons lost or gained, if more than one. For example: H^+ , SO_4^{2-} .

JFETS: Junction Field Effect Transistor. The common transistor is called a junction transistor, and it was the key device which led to the solid state electronics revolution. In application, the junction transistor has the disadvantage of low input impedance because the base of the transistor is the signal input and the base-emitter [diode](#) is forward biased. Another device achieved transistor action with the input diode junction reversed biased, and this device is called a "field effect transistor" or a "junction field effect transistor", JFET. With the reverse biased input junction, it has very high input impedance. Having high input impedance minimizes the interference with or "loading" of the signal source when a measurement is made.

JOULE: As a rough guide, 1 joule is the amount of energy required to lift a one kilogram object up by a height of about 100 centimeters on the surface of the Earth, by the most efficient method.

LASER: A LASER (acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation) is an optical source that emits photons in a coherent beam.

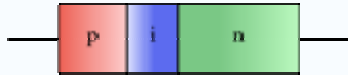
NEUTRONS: Neutrons, which have no charge, are about 1838 times more massive than [electrons](#).

PELTIER EFFECT: The Peltier effect is the reverse of the Seebeck effect; a creation of a heat difference from an electric voltage. It occurs when a current is passed through two dissimilar metals or semiconductors that are connected to each other at two junctions (Peltier junctions). The current drives a transfer of heat from one junction to the other: one junction cools off while the other heats up; as a result, the effect is often used for [thermoelectric](#) cooling. An interesting consequence of this effect is that the direction of heat transfer is controlled by the polarity of the current; reversing the polarity will change the direction of transfer and thus the sign of the heat absorbed.

PHASE VELOCITY: The rate at which the phase of the waveform is moving.

PHOTON: In physics, the photon is the elementary particle responsible for [electromagnetic](#) phenomena. It mediates electromagnetic interactions and makes up all forms of light. The photon has zero *invariant* mass and travels at the constant speed c , the speed of light in empty space. However, in the presence of matter, a photon can be slowed or even absorbed, transferring energy and momentum proportional to its [frequency](#).

PIN DIODE:



Layers of a PIN [diode](#)

PIN diode (p-type, intrinsic, n-type diode) is a diode with a wide, undoped intrinsic semiconductor region between p-type semiconductor and n-type semiconductor regions.

PLASMA: A collection of gas-like ions, or even a gas containing a proportion of charged particles, is called plasma. The free electric charges make the plasma electrically conductive so that it responds strongly to [electromagnetic](#) fields.

POLARIZER: A device that converts unpolarized or a mixed beam of [electromagnetic](#) waves (such as [laser](#) light) into a beam with a single polarization state. Polarizers can be divided into two general categories: **absorptive polarizers**, where the unwanted polarization states are absorbed by the device, and **beam-splitting polarizers**, where the unpolarized beam is split into two beams with opposite polarization states.

PROTONS: Protons, which have a positive charge, and are about 1836 times more massive than [electrons](#).

RAD: The rad is a unit of radiation dose. *Rad* stands for "**r**adiation **a**bsorbed **d**ose". The rad is a unit of radiation absorption defined in terms of the energy actually deposited in the tissue. One rad is an absorbed dose of 0.01 [joules](#) of energy per kilogram of tissue.

RADIATION: Radiation in physics is the process of emitting energy in the form of waves or particles. Various types of radiation can be distinguished, depending on the properties of the emitted energy/matter, the type of the emission source, properties and purposes of the emission, etc.

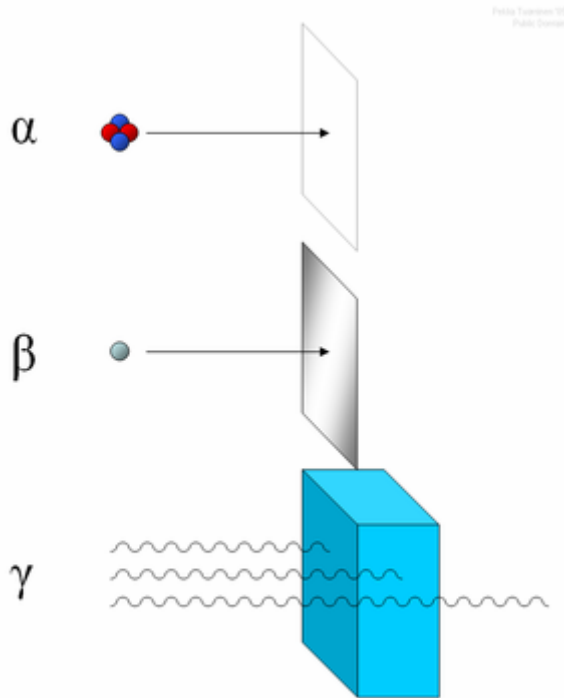
TYPES OF RADIATION

X-RAYS: **X-rays** (or Röntgen rays) are a form of [electromagnetic](#) radiation with a wavelength in the range of 10 to 0.01 [nanometers](#). X-rays are a form of ionizing radiation

and as such can be dangerous. X-rays are low a spectrum, low intensity form of gamma-rays (γ).

ALPHA PARTICLES: Alpha particles (α) are a highly [ionizing](#) form of particle radiation that has a low penetration. They consist of two [protons](#) and two [neutrons](#) bound together into a particle identical to a helium nucleus (He^{2+}).

BETA PARTICLES: Beta particles (β) are high-energy, high-speed [electrons](#), and are a form of ionizing radiation. The production of beta particles is termed beta decay.



Alpha radiation consists of helium nuclei and is stopped by a sheet of paper. Beta radiation, consisting of [electrons](#), is stopped by an aluminum plate. Gamma (and x-ray) radiation is eventually absorbed as they penetrate a dense material, such as lead.

Radiation Exposure Table of exposure levels and symptoms

0.05–0.2 Sv (5–20 REM)

No symptoms. A few researchers contend that low dose radiation may be beneficial. 50 mSv is the yearly federal limit for radiation workers in the United States.

0.2–0.5 Sv (20–50 REM)

No noticeable symptoms. Red blood cell count decreases temporarily.

0.5–1 Sv (50–100 REM)

Causes mild radiation sickness with headache and increased risk of infection due to disruption of immunity cells. Temporary male sterility is possible.

1–2 Sv (100–200 REM)

Light radiation poisoning, 10% fatality after 30 days. Typical symptoms include mild to moderate nausea, with occasional vomiting, beginning 3 to 6 hours after irradiation and lasting for up to one day. This is followed by a 10 to 14 day latent phase, after which light symptoms like general illness and fatigue appear. The immune system is depressed, with convalescence extended and increased risk of infection. Temporary male sterility is common. Spontaneous abortion or stillbirth will occur in pregnant women.

2–3 Sv (200–300 REM)

Severe radiation poisoning, 35% fatality after 30 days. Nausea is common, with 50% risk of vomiting at 2.8 Sv. Symptoms onset at 1 to 6 hours after irradiation and last for 1 to 2 days. After that, there is a 7 to 14 day latent phase, after which the following symptoms appear: loss of hair all over the body, fatigue and general illness. There is a massive loss of leukocytes (white blood cells), greatly increasing the risk of infection. Permanent female sterility is possible. Convalescence takes one to several months.

3–4 Sv (300–400 REM)

Severe radiation poisoning, 50% fatality after 30 day. Other symptoms are similar to the 2–3 Sv dose, with uncontrollable bleeding in the mouth, under the skin and in the kidneys after the latent phase.

4–6 Sv (400–600 REM)

Acute radiation poisoning, 60% fatality after 30 days. Fatality increases from 60% at 4.5 Sv to 90% at 6 Sv (unless there is intense medical care). Symptoms start half an hour to two hours after irradiation and last for up to 2 days. After that, there is a 7 to 14 day latent phase, after which generally the same symptoms appear as with 3-4 Sv irradiation, with increased intensity. Female sterility is common at this point. Convalescence takes several months to a year. The primary causes of death (in general 2 to 12 weeks after irradiation) are infections and internal bleeding.

6–10 Sv (600–1,000 REM)

Acute radiation poisoning, near 100% fatality after 14 days. Survival depends on intense medical care. Bone marrow is nearly or completely destroyed, so a bone marrow transplant is required. Gastric and intestinal tissues are severely damaged. Symptoms start 15 to 30 minutes after irradiation and last for up to 2 days. Subsequently, there is a 5

to 10 day latent phase, after which the person dies of infection or internal bleeding. Recovery would take several years and probably would never be complete.

Devair Alves Ferreira received a dose of approximately 7.0 Sv (700 REM) during the Goiânia accident and survived, partially due to his fractionated exposure.

10–50 Sv (1,000–5,000 REM)

Acute radiation poisoning, 100% fatality after 7 days. An exposure this high leads to spontaneous symptoms after 5 to 30 minutes. After follows powerful fatigue and immediate nausea caused by direct activation of chemical receptors in the brain by the irradiation, there is a period of several days of comparative well-being, called the latent (or "walking ghost") phase. After that, cell death in the gastric and intestinal tissue, causing massive diarrhea, intestinal bleeding and loss of water, leads to water-electrolyte imbalance. Death sets in with delirium and coma due to breakdown of circulation. Death is inevitable; the only treatment that can be offered is pain therapy.

Louis Slotin was exposed to approximately 21 Sv in a criticality accident on 21 May 1946, and died nine days later on 30 May.

REFRACTIVE INDEX: The refractive index of a material is the factor by which the [phase velocity](#) of [electromagnetic radiation](#) is slowed in that material, relative to its velocity in a [vacuum](#).

REM: The [röntgen](#) (roentgen) [equivalent in man](#) or **rem** is a unit of [radiation](#) dose. It is the product of the absorbed dose in röntgens (R) and the biological efficiency of the radiation. A rem is a large amount of radiation, so the [millirem](#) (mrem), which is one thousandth of a rem, is often used for the dosages commonly encountered, such as the amount of radiation received from medical [x-rays](#) and background sources.

SCALE:

10ⁿ	Prefix	Symbol	Short scale	Decimal equivalent
10 ¹²	tera	T	Trillion	1 000 000 000 000
10 ⁹	giga	G	Billion	1 000 000 000
10 ⁶	mega	M	Million	1 000 000

10^3	kilo	k	Thousand	1 000
10^2	hecto	h	Hundred	100
10^1	deca	da	Ten	10
10^0	(none)	(none)	One	1
10^{-1}	deci	d	Tenth	0.1
10^{-2}	centi	c	Hundredth	0.01
10^{-3}	milli	m	Thousandth	0.001
10^{-6}	micro	μ (u)	Millionth	0.000 001
10^{-9}	nano	n	Billionth	0.000 000 001
10^{-12}	pico	p	Trillionth	0.000 000 000 001

SIEVERT: The sievert (symbol: Sv) is a unit of dose equivalent. It attempts to reflect the biological effects of [radiation](#) as opposed to the physical aspects.

SPUTTERING: Sputtering is a physical process where atoms in a solid target material are ejected into the gas phase due to bombardment of the material by energetic [ions](#). It is commonly used for [thin-film deposition](#). Sputtering is largely driven by a momentum exchange between the ions and atoms in the material, due to collisions. The process can be thought of as atomic billiards, with the ion (cue ball) striking a large cluster of close-packed atoms (billiard balls). Although the first collision pushes atoms deeper into the cluster, subsequent collisions between the atoms can result in some of the atoms near the surface being ejected away from the cluster. The number of atoms ejected from the surface per incident ion is called the *sputter yield* and is an important measure of the efficiency of the sputtering process. Other things the sputter yield depends on are the

energy of the incident ions, the masses of the ions and target atoms, and the binding energy of atoms in the solid.

The [ions](#) for the sputtering process are supplied by a [plasma](#) that is induced in the sputtering equipment. In practice a variety of techniques are used to modify the [plasma](#) properties, especially ion density, to achieve the optimum sputtering conditions, including usage of RF (radio frequency) alternating current, utilization of magnetic fields, and application of a bias voltage to the target.

For thin film deposition

Sputter deposition is a method of depositing thin films by sputtering a block of source material onto a substrate. Sputtered atoms ejected into the gas phase are not in their thermodynamic equilibrium state, and tend to deposit on all surfaces in the [vacuum](#) chamber. A substrate (such as a wafer) placed in the chamber will be coated with a thin film. Sputtering usually uses argon [plasma](#).

TEC (PELTIER COOLER): A [Peltier](#) cooler heater or [thermoelectric](#) heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other. Peltier coolers are also called *thermo-electric coolers* (TEC).

TEMPERATURE CONVERSIONS:

	kelvin	Celsius	Fahrenheit
Absolute zero	0 K	-273.15 °C	-459.67 °F
Melting point of ice	273.15 K	0 °C	32 °F
Water's boiling point	373.1339 K	99.9839 °C	211.9710 °F

Kelvin temperature conversion formulas		
To find	From	Formula
Celsius	kelvin	$^{\circ}\text{C} = \text{K} - 273.15$
kelvin	Celsius	$\text{K} = ^{\circ}\text{C} + 273.15$
Fahrenheit	kelvin	$^{\circ}\text{F} = (\text{K} \times 1.8) - 459.67$
kelvin	Fahrenheit	$\text{K} = (^{\circ}\text{F} + 459.67) \div 1.8$

electronvolts	kelvin	$eV \approx K \div 11,604.5$
kelvin	electronvolts	$K \approx eV \times 11,604.5$

THERMOELECTRIC EFFECT: The [Peltier](#)–Seebeck effect, or thermoelectric effect, is the direct conversion of thermal differentials to electric voltage and vice versa.

TORR: Torr or [millimeter](#) of mercury (mmHg) is a unit of pressure. It is the atmospheric pressure that supports a column of mercury 1 millimeter high. Normal atmospheric pressures can support 760mm of mercury, so 1/760 of an atmosphere is a convenient measurement point expressed as torr.

VACUUM: A vacuum is a volume of space that is almost empty of matter, so that gaseous pressure is much less than standard atmospheric pressure. The quality of a vacuum is measured by how closely it approaches a perfect vacuum. The residual gas pressure is the primary indicator of quality, and it is most commonly measured in units of [torr](#). Lower pressures indicate higher quality. The lowest pressure currently achievable in a laboratory is about 10^{-13} Torr.

OUTGASSING

Evaporation into a vacuum is called outgassing. All materials, solid or liquid, have a small vapor pressure, and their outgassing becomes important when the vacuum pressure falls below this vapor pressure. In man-made systems, outgassing has the same effect as a leak and can limit the achievable vacuum. Outgassing products may condense on nearby colder surfaces, which can be troublesome if they obscure optical instruments or react with other materials.

The most common outgassing product in man-made vacuum systems is water absorbed by chamber materials. It can be reduced by desiccating or baking the chamber, and removing absorbent materials. High vacuum systems must be clean and free of organic matter to minimize outgassing.

Ultra-high vacuums are usually baked to temporarily raise the vapor pressure of all outgassing materials in the system and boil them off. Once the bulk of the outgassing materials are boiled off and evacuated, the system may be cooled to lower vapor pressures and minimize residual outgassing during actual operation. Some systems are cooled well below room temperature by liquid nitrogen to shut down residual outgassing and simultaneously [cryopump](#) the system.

One of the most important parameters is the **mean free path** (MFP) of residual gases, which indicates the average distance that molecules will travel between collisions with each other. Vacuum quality is subdivided into ranges according to the technology

required to achieve it or measure it. These ranges do not have universally agreed upon definitions, but a typical distribution is as follows:

Atmospheric pressure	760 Torr
Low vacuum	760 to 25 Torr
Medium vacuum	25 to 1×10^{-3} Torr
High vacuum	1×10^{-3} to 1×10^{-9} Torr
Ultra high vacuum	1×10^{-9} to 1×10^{-12} Torr
Extremely high vacuum	$< 1 \times 10^{-12}$ Torr
Outer Space	1×10^{-6} to $< 3 \times 10^{-17}$ Torr
Perfect vacuum	0 Torr

- **Atmospheric pressure** is standardized at 760 Torr.
- **Low vacuum**, also called *rough vacuum* or *coarse vacuum*, is vacuum that can be achieved or measured with rudimentary equipment such as a vacuum cleaner and a liquid column manometer.
- **Medium vacuum** is vacuum that can be achieved with a single pump, but is too low to measure with a liquid or mechanical manometer.
- **High vacuum** is a vacuum where the **MFP** of residual gases is longer than the size of the chamber or of the object under test. High vacuum usually requires multi-stage pumping and ion gauge measurement. Some texts differentiate between high vacuum and *very high vacuum*.
- **Ultra high vacuum** requires baking the chamber to remove trace gases, and other special procedures.
- **Deep space** is emptier than any artificial vacuum that we can create.
- **Perfect vacuum** is an ideal state that cannot be obtained in a laboratory, or even in outer space.

Examples

Vacuum cleaner	(600 Torr)
liquid ring vacuum pump	(24 Torr)
freeze drying	(1 to 0.1 Torr)
Incandescent light bulb	(0.1 to 0.01 Torr)
Thermos bottle	(10^{-2} to 10^{-3} Torr)
Near earth outer space	(10^{-6} Torr)
Cryopumped MBE chamber	(10^{-9} Torr to 10^{-11} Torr)
Pressure on the Moon	(10^{-11} Torr)
Interstellar space	(10^{-17} Torr)

VACUUM PUMPS

Pumps can be broadly categorized according to three techniques:

- **Positive displacement** pumps use a mechanism to repeatedly expand a cavity, allow gases to flow in from the chamber, seal off the cavity, and exhaust it to the atmosphere.
- **Momentum transfer** pumps, also called **molecular pumps**, use high speed jets of dense fluid or high speed rotating blades to knock gaseous molecules out of the chamber.
- **Entrapment** pumps capture gases in a solid or absorbed state. This includes [cryopumps](#), **getters**, and **Ion pumps**.

Cryopump

A cryopump is a vacuum pump that traps gases and vapors by condensing them on a cold surface. They are only effective on selective gases, depending on the freezing and boiling points of the gas relative to the cryopump's temperature. They are sometimes used to block particular contaminants. Cryopumps are commonly cooled by liquid nitrogen, or stand-alone versions may include a built-in cryocooler. Baffles are often attached to the cold head to expand the surface area available for condensation, but they also increase the radiative heat uptake of the cryopump. Over time, the surface eventually saturates with condensate and the pumping speed gradually drops to zero. It will hold the trapped gases as long as it remains cold, but it will not condense fresh gases from leaks until it is [regenerated](#). Saturation happens very quickly in low vacuums, so cryopumps are usually only used in high or ultrahigh vacuum systems.

Regeneration of a cryopump is the process of evaporating the trapped gases. This can be done at room temperature and pressure, or the process can be made more complete by exposure to vacuum and faster by elevated temperatures. Best practice is to heat the whole chamber under vacuum to the highest temperature allowed by the materials, allow time for outgassing products to be exhausted by the mechanical pumps, and then cool and use the cryopump without breaking the vacuum.

WAVELENGTH: The '*wavelength*' is the distance between repeating units of a wave pattern. It is commonly designated by the Greek letter *lambda* (λ). In a sine wave, the wavelength is the distance between the midpoints of the wave.