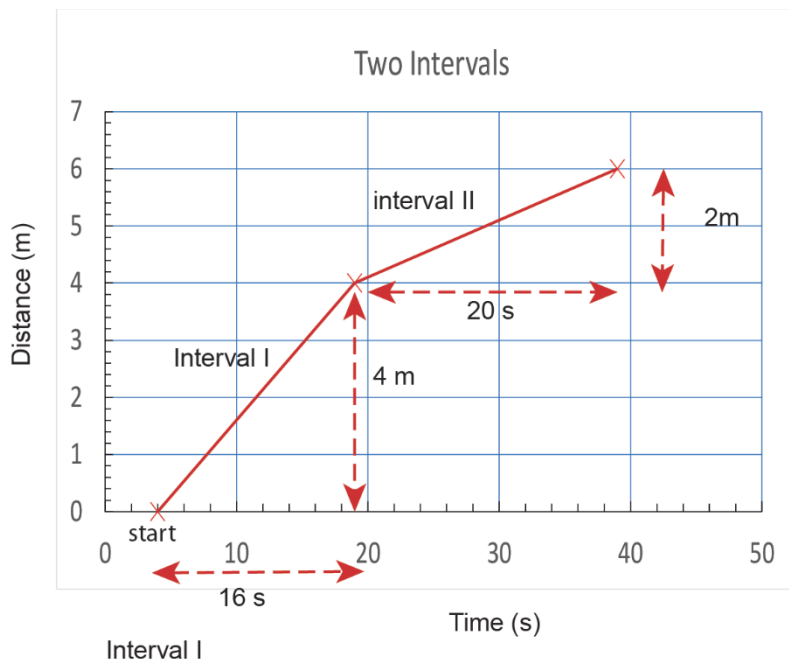
Dynamics

Motion of objects: point particles, spheres, satellites in orbit around the earth or sun, galaxies, expansion of the universe etc.

A large number of the questions raised in physics and often easily solved concerns the motion of objects; is it steady or changing, what causes changes, what can we predict?

Definitions

Speed: $V = \frac{distance}{time}$ meter/second (m/s)



Interval I
average speed =4/16 = 0.25 m/s

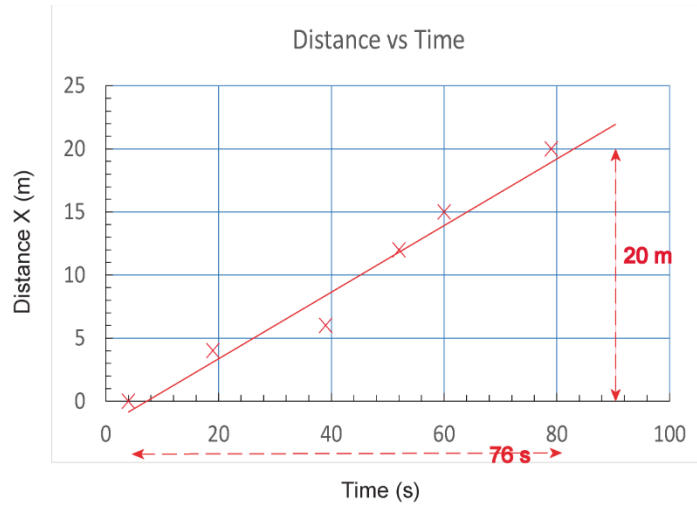
interval II
average speed = 0.10 m/s

The speed changed in magnitude. Increase=acceleration. Decrease =deceleration

Questions: What would cause such a change? (Newton: Force but depends on inertia (mass) also)

What about just a change in direction but speed constant? E.g. motion of Earth around Sun. That ALSO requires a force.)

Average speed



average speed = 20/76 = 0.26 m/s

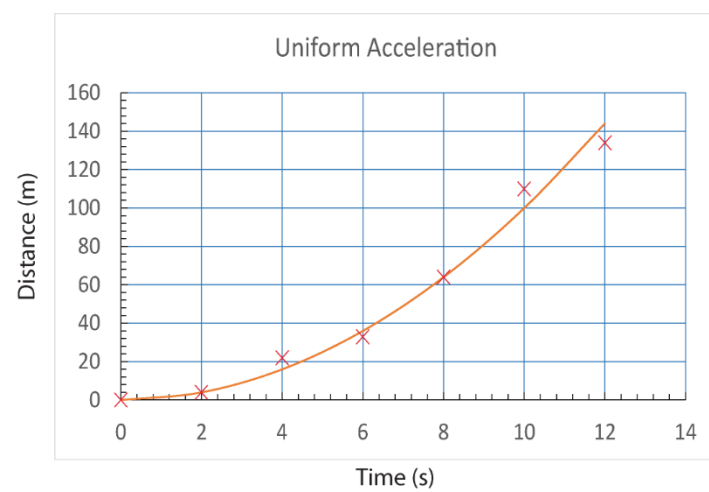
Overall: X = V_{avg} * t

Can predict where object is in 24 hours X =3600*0.26 = 936 m (assuming no changes)

Note some errors in measurements with respect to average speed. Experimenters need to identify origin of these errors and justify as errors and not a physics effect.

Speed changing constantly at same rate

Uniform acceleration: a meters/second/second (m/s^2)



$Distance$: $X = \frac{1}{2}at^2$ Parabola

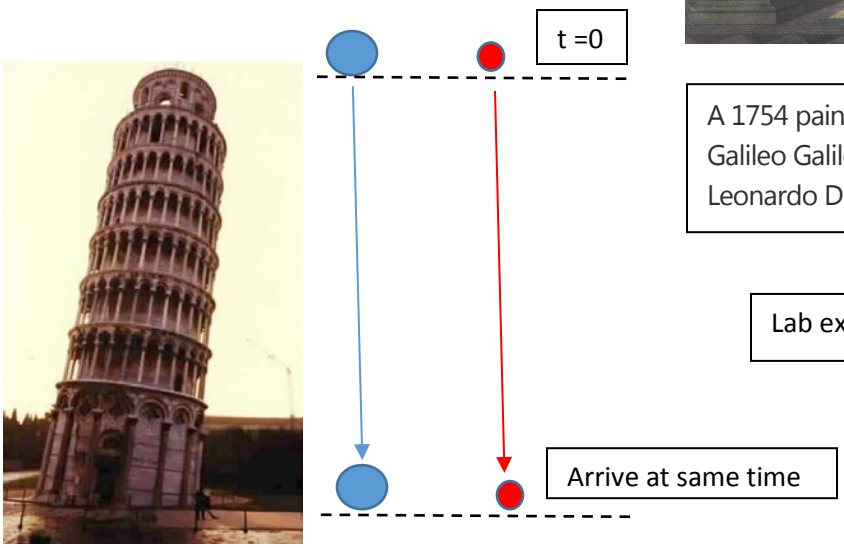
Example of constant acceleration

Motion under gravity. $g = 9.8 m/s^2$

*Attributed first to **Galileo Galilei***

All objects fall under gravity with the same acceleration.

independent of mass m



A 1754 painting by H. Detouche shows Galileo Galilei displaying his telescope to Leonardo Donato and the Venetian Senate.

Lab experiment on this topic

Credit: media4.picsearch.com

Need Newton's Laws and concepts .... could predict events (revolutionary), also developed calculus

FORCE: F= ma

Concept of inertia Mass m (kilograms)

Concept of Force = rate of change of momentum mass * velovity, P =mV

Newton went further to show from Kepler's laws obervation of planetary motion

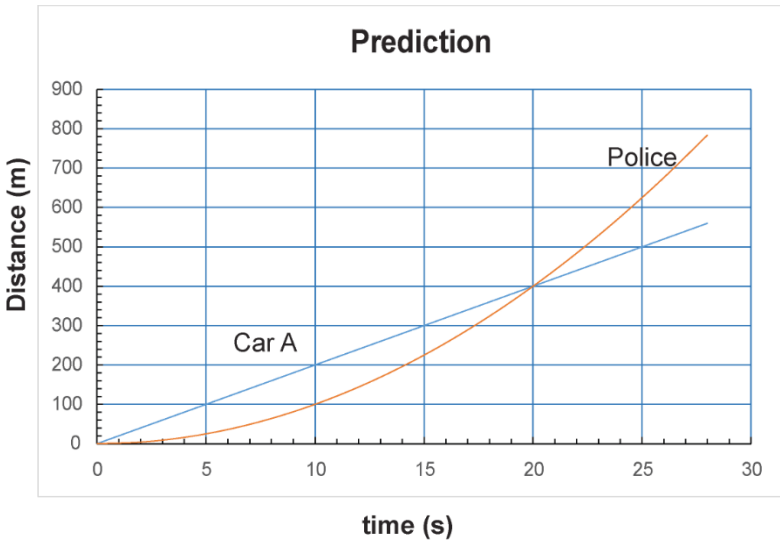
that force of gravity $F_G = GMm/R^2$ R= separation of two masses m and M

G = universal constant

Newton's Laws

1. **Every body continues in state of motion UNLESS acted on by a force (Galileo's principal of inertia)**
2. **Change in motion (change in momentuim) = impressed force and in direction of that force (pure Newton)**
3. **To every action, there is an equal and opposite reaction (mutual actions of two bodioes always equal in magnitude and opposite) (momentum conservation)**

Prediction



A car driving at 20 m/s (72 km/h) passes a stationary police vehicle. At the moment of passing the police vehlce accerates at $2m/s^2$. When dioes the police car catch up with the car?

Car A: x =2t = blue line (constant speed)
Police (red) $x=(1/2)2t^2 =t^2$ red line (parabola)
Equal distance at t=20 s.

Can continue prediction for complicated objects, orbits of plants and comets: prediction of return of Halley's comet (actually calculated by Halley using Newton's Laws).

Australian Astronomical Observatory
March 8. 1986, Period ~ 76 years

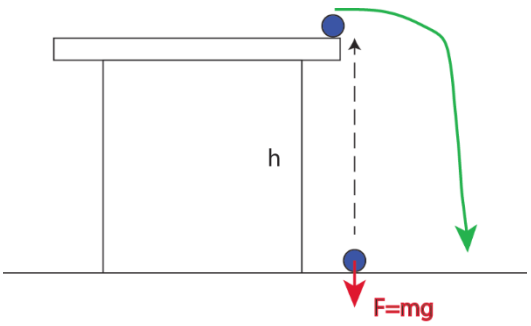
Energy and Work

You keep both Rule and Energy in view,
Much power in each, most in the balanced two:
Ferocity existing in the fence
Built by an exercised intelligence……

Thorn Gunn (An early poem written to his mentor Jay Parini)

To complete the use of Newton's law we need something new. It takes something to create a force that makes a car move and out it into a state of motion, furthermore that sate of motion can be sued to A machine can be used to lift an object to a height against the force of gravity. Today we know this as an energy. To lift a mass m against the force of gravity, F=mg, we must expend energy by doing work.

The work done =Force* displacement in direction of force, W = mgh.



Work = F*h = mgh = (1/2)mV^2 = KE

$$Use\ dynamics\ (from\ above)\quad V = gt, \qquad h = \frac{1}{2}gt^2 = \frac{V^2}{2g}$$

If we kick the ball off the shelf it acquires velocity (kinetic energy) before it hits the floor.

Work converted to kinetic energy.

Conservation of Energy (if we can account for all forms of energy in a problem).

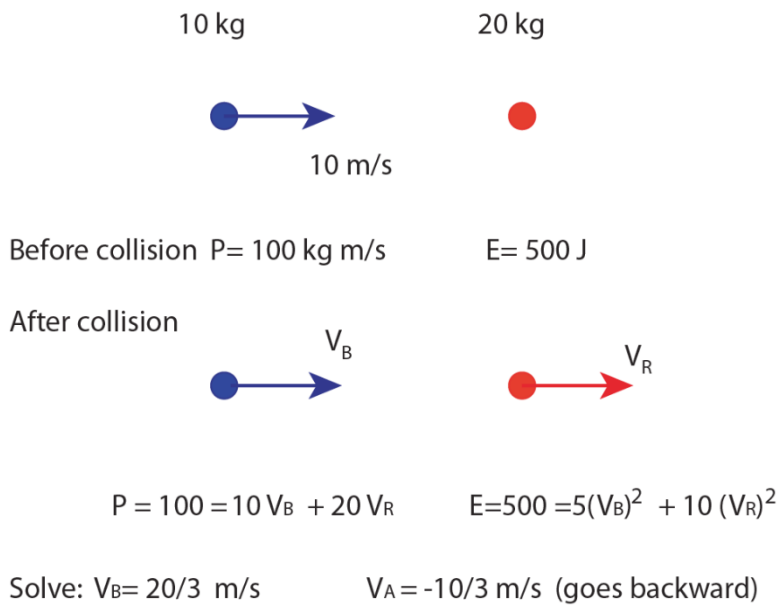
We can use this principle to solve more complicate problems.

Energy cannot be created or destroyed. It can be converted from one form of energy to another or transferred from one object to another.

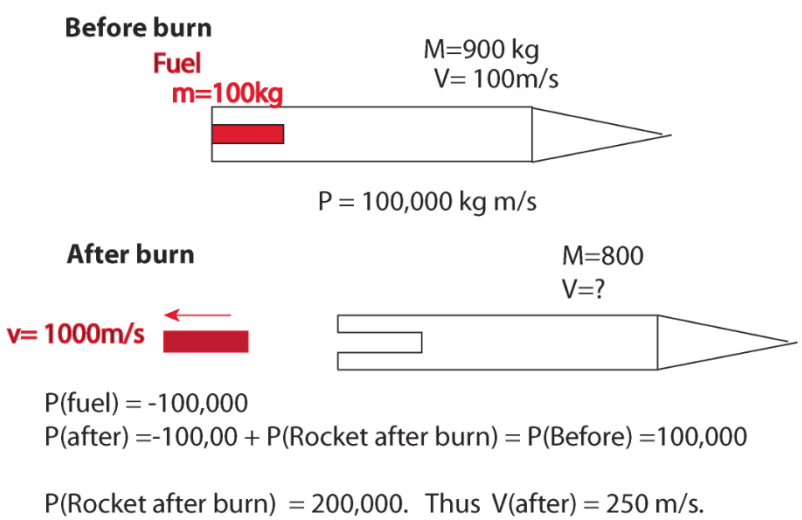
Conservation of Momentum (Newton)

Must be careful about sign

Collisions



Rockets



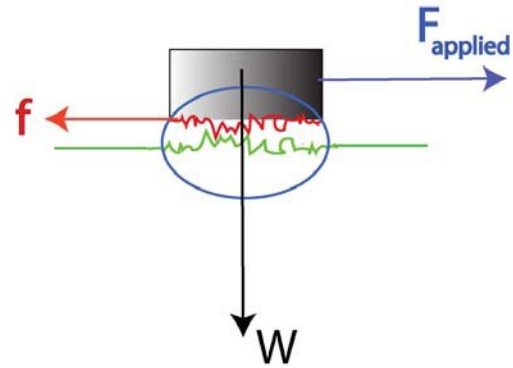
Emily Dickison

Hope is a strange invention --
A Patent of the Heart --
In unremitting action
Yet never wearing out --

Of this electric Adjunct
Not anything is known
But its unique momentum
Embellish all we own --

LECTURE PHY 1033C

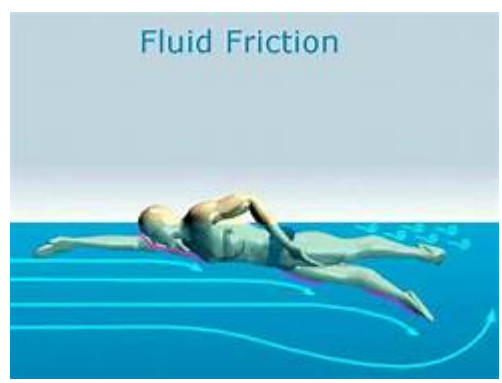
FRICTION



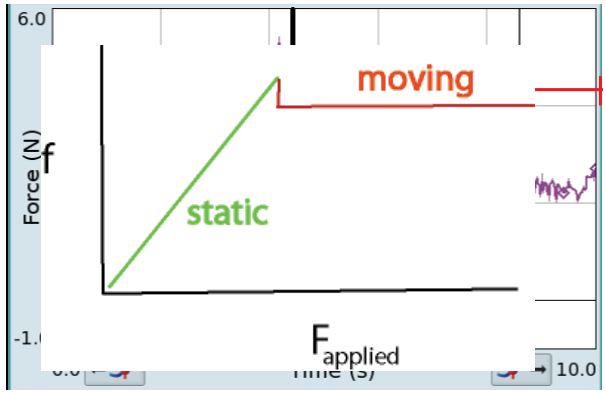
Force of friction proportional to force NORMAL to motion

μ = coefficient of friction $f=\mu W$

Rubber on concrete	$\mu \approx$ **0.8**
Steel on steel	**0.07**
Skater on ice	**0.02**



Static versus sliding friction



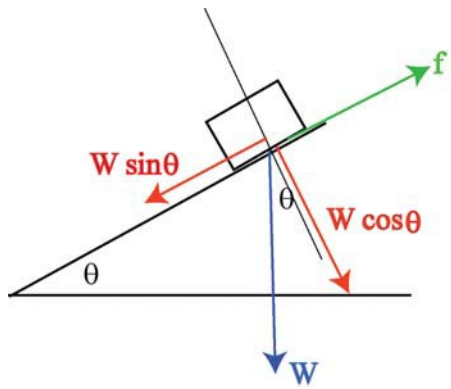
Wikipedia

Object does not move until

$F_{applied}$ overcomes static friction

Inclined plane

How to measure friction



Force normal to plane

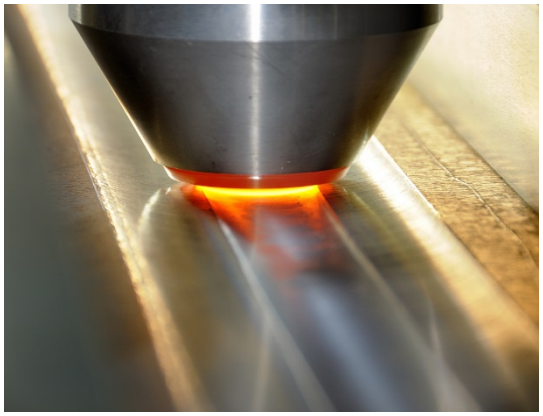
$F = W\cos\theta$

Friction $f = \mu W\cos\theta$

SLIDES when $W\sin\theta = f$

OR $\tan\theta = \mu$

Generate heat



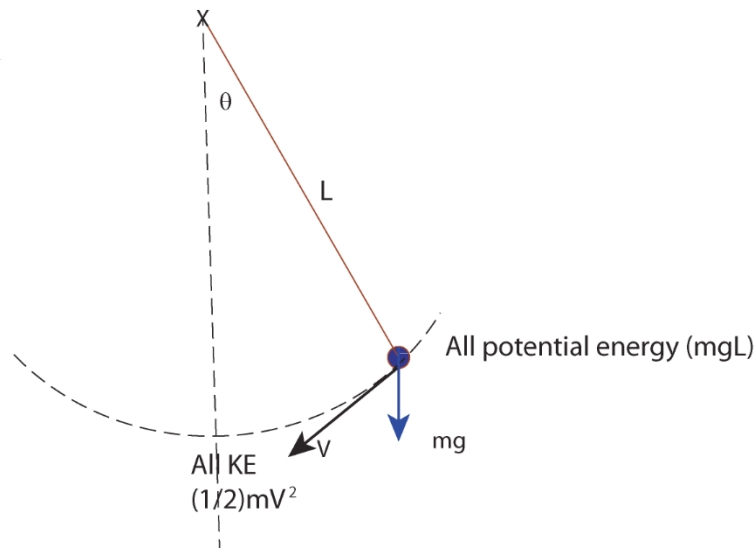
Force of friction * distance
= work → HEAT

Anti-skid braking

Sense rotation of wheels slowing, and car slides,

--- pulse brake pads off and on rapidly to control skid

Pendulum



For small θ,

oscillatory motion

$$\theta = \theta_{max} sin\sqrt{\frac{g}{L}}t$$

Period $\boldsymbol{T = 2\pi\sqrt{\frac{L}{g}}}$

Can serve as a clock for fixed g and fixed L

Example

Grandfather clock L = 2m, g=9.8m/s^2

T = 2.84 s.

Homework:

A pendulum clock that has a period of 0.5 sec on Earth is moved to a small satellite where g =g(Earth)/9. What is the new period of the clock?

OR

Write a short essay (1 page maximum) on how pendulum clocks are used around the world (Big Ben and all that)

Ideal Gas Laws

Boyles Law $\boldsymbol{P} \propto \frac{\mathbf{1}}{\boldsymbol{V}}$ Pressure inversely proportional to volume **AT** constant T (temperature) and N (number of molecules)

Robert Boyle [1627 –1691](https://en.wikipedia.org/wiki/Robert_Boyle) Irish chemist/philosopher. Authiored *The Sceptical Chymist* regarded as a cornerstone book in the field of chemistry.

Charles Law $\boldsymbol{V} \propto \boldsymbol{T}$ **Volume proportional to temperature if P and n are constant. But T must be units of Kelvin. K=C +273. Concept of absolute zero**

Jacques Alexandre César Charles (November 12, 1746 – April 7, 1823) was a French inventor, scientist, mathematician, and balloonist. Charles wrote almost nothing about mathematics, and most of what has been credited to him was due to mistaking him with another Jacques Charles, also a member of the Paris Academy of Sciences, entering on May 12, 1785. He was sometimes called Charles the Geometer. (See J. B. Gough, Charles the Obscure, Isis 70, #254, pgs 576-579) Charles and the Robert brothers launched the world's first unmanned hydrogen-filled gas balloon in August 1783.

[https://en.wikipedia.org/wiki/Jacques_Charles]

Avogadro's Law $V \propto N$ **Volume is proportional to amount of gas (at constant T and constant P)**

https://en.wikipedia.org/wiki/Amedeo_Avogadro

Amedeo Carlo Avogadro[1] (1776 -1856), Count of Quaregna and Cerreto, was an Italian scientist, most noted for his contribution to molecular theory now known as Avogadro's law, which states that equal volumes of gases under the same conditions of temperature and pressure will contain equal numbers of molecules. In tribute to him, the number of elementary entities (atoms, molecules, ions or other particles) in 1 mole of a substance, $6.022140857(74)\times10^{23}$, is known as the Avogadro constant, one of the seven SI base units and represented by N_A.

IDEAL GAS LAW PV=nRT

Pressure in Pascals (Pa), V in m3, T in Kelvin

R is the gas constant = 8.31 Joules/mole K

VERY USEFUL

Examples

A)

1 m3 of helium gas in a steel cylinder at 0 C is heated to 200 C. If the initial pressure was 100 kPa (1 atmos approx..) what is the final pressure.

V = constant

P(final) = P(initial) * T(final)/T(initial)

= 100 * 473/273 = 173 Pa = 1.73 atmos.

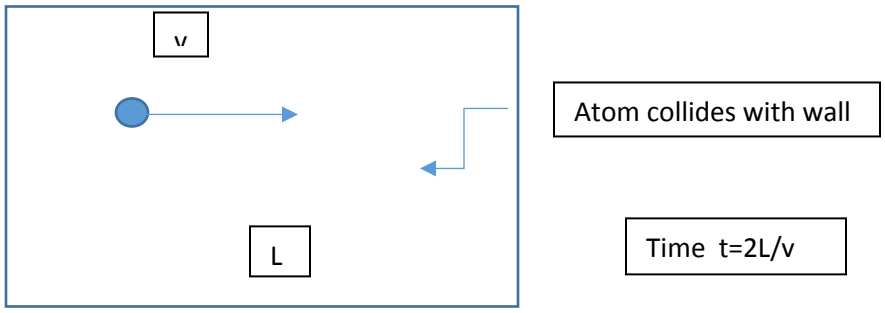
B) The pressure of a 100 cm3 cylinder of N_2 gas at 20 C has a pressure of 100 atmos. What is the mass of N_2 in the cylinder?

m=M (PV/RT) M is the molecular weight =28kg/kmole

R = 83100 J/kmole K

Calculate m = 12 grams. You can determine how much gas is in cylinder by weighing it. (Need to know empty weight of cylinder.)

Kinetic Theory of Gases



Change in momentum =impulse = 2mv = Force x time =F 2L/v

Average force (per atom/molecule) = F = mV^2/L

No. molecules = nLA where n is no per unit volume and A = Area of wall

Pressure exerted by gas on wall P = F/A = nm $\langle v^2 \rangle_{avg}$

Find P= (1/3) nmv^2

BUT experimental gas laws show PV =NRT, N is the number of moles of gas

OR (1/2) mV^2 = (3/2)$k_B T$ T is JUST a measure of internal energy

Electricity

Static electricity (charges)

Electrical current (circuits)

Magnetism

St. Elmos fire (actually a plasma at sharp points on ships mast generated in thunderstorm or near volcanic eruption eruption

STATIC ELECTRICITY

Historical. Amber rubbed with fur attracted light objects; cat fur, paper, polystyrene balls…

Attributed to Greek mathematician Thales of Miletus (624-546 BC) [first philosopher in Greek tradition][used geometry to calculate height of pyramids]

Everyday occurrences:

Lightning, sparks (matches), St. Elmos fire….

Lightning over central Florida (Universities Research Association)

Origin is in the structure of atoms

Greek: *ἤλεκτρον* "**elektron" for amber**

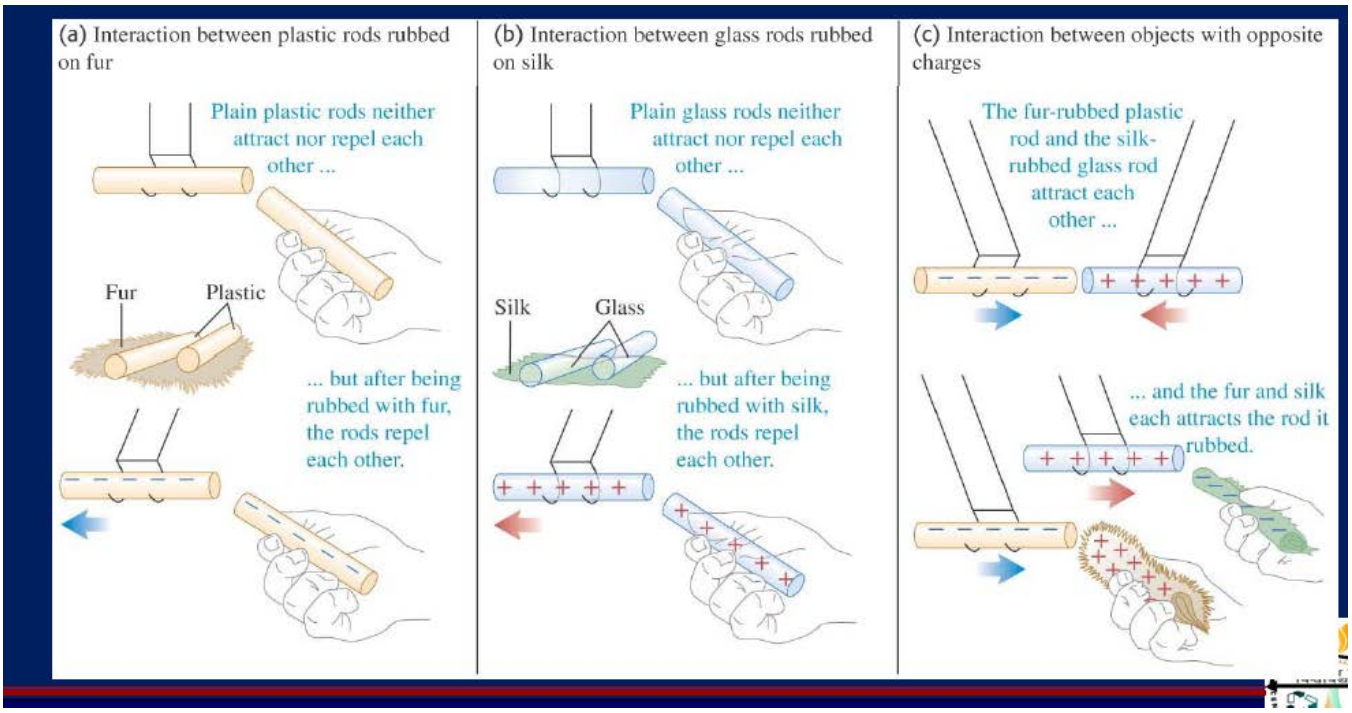
Atoms electrons (-ve charge) in outer "orbits" around nucleus (+ve charge)

Rub plastic rod with fur, outer electrons stripped from atoms and end up on rod. Two such rods repel (like charges repel).

Rub glass rod with silk, electrons stripped from glass, two such glass rods repel but the glass rod and the plastic rod attract. TWO types of charges.

Convention: electron has negative charge. Object deficient in electrons will hold a positive charge.

Like charges repel, unlike charges attract.



Credit: P. Ravindran, PHY041 January 2103xperiments

Charles-Augustin de Coulomb (1736-1860), French military engineer, resigned commission at start of French revolution.

Portrait by Louis Hierle in 1894

Coulomb's Law

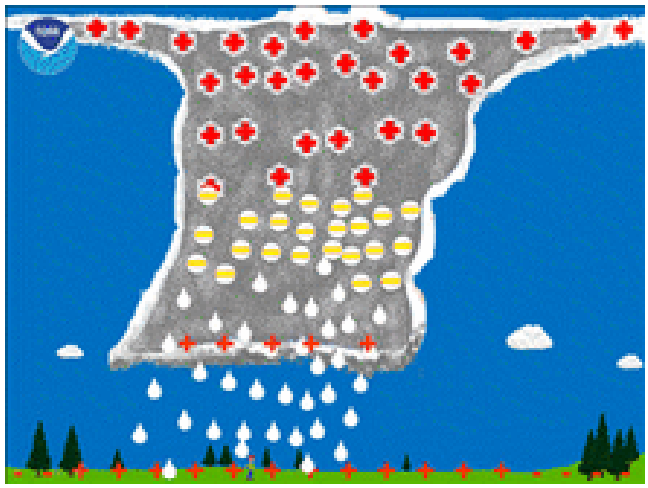
$$F = K\,\frac{Q_1 Q_2}{R^2}$$

Q_1, Q_2 electric charges in coulombs, R distance(meters), F in newtons.

Inverse square law like gravitation BUT K (=9*10^9); huge in comparison

Electrical forces are STRONG (Hence value in applications and DANGERS)

How do clouds become charged?

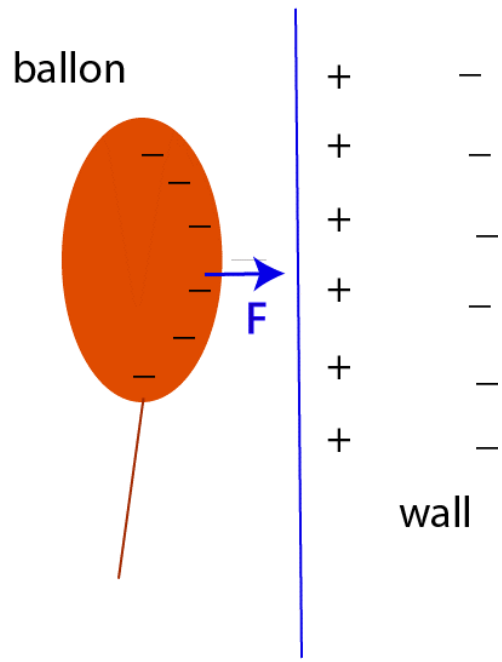


Small ice particles move up while larger soft hail (graulen) moves down. The small solid particles lose electrons and become positively charged. Top of cloud +ve and spreads out to anvil shape.

https://upload.wikimedia.org/wikipedia/commons/c/cf/Charged_cloud_animation_4a.gif

How does a charged balloon stick to a wall.

Balloon is initially charged negatively by rubbing with fur. As it is moved toward the wall it repels mobile electrons (-ve charges), leaving positive charge at the surface of the wall. Because force proportional to $1/R^2$, attractive force wins and balloon is attracted by force F to ball and sticks there until charge dissipates.



Magnetism

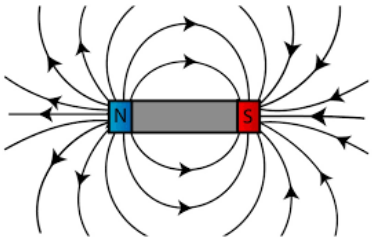
Known to the early Chinese in 12th century, and in some detail by ancient Greeks who observed that certain stones “lodestones” attracted pieces of iron. Lodestones were found in the coastal area of “Magnesia” in Thessaly at the beginning of the modern era. The name of magnetism derives from magnesia.

William Gilbert, physician to Elizabeth 1, made magnets by rubbing Fe against lodestones and was first to recognize the Earth was a large magnet and that lodestones always pointed north-south. Hence the use of magnetic compasses. Book “De Magnete” 1600. The English word "electricity" was first used in 1646 by Sir Thomas Browne, derived from Gilbert's 1600 New Latin *electricus*, meaning "like amber".

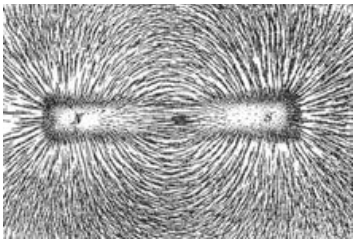
Gilbert demonstrates a “lodestone” compass to ER 1. Painting by Auckland Hunt.

John Mitchell (1750) found that like electric forces magnetic forces decrease with separation (confirmed by Coulomb).

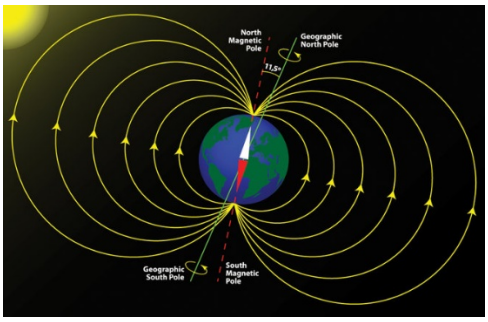
Link between electricity and magnetism discovered by Hans Christian Oersted (1820) who noted a wire carrying an electric current affected a magnetic compass. Confirmed by Andre Marie Ampere who shows electric currents were source of magnetic phenomena.



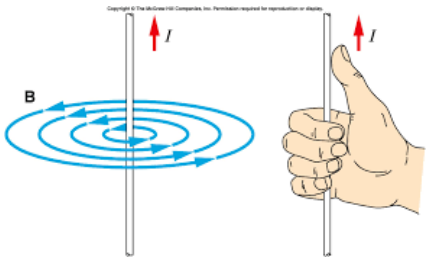
Force fields emanating from a bar magnet, showing Nth and Sth poles (credit: Justscience 2017)



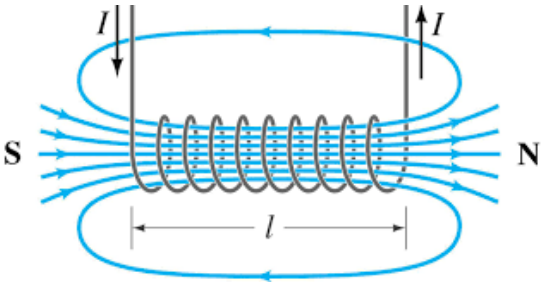
Showing magnetic force fields with Fe filings (Wikipedia.org.)



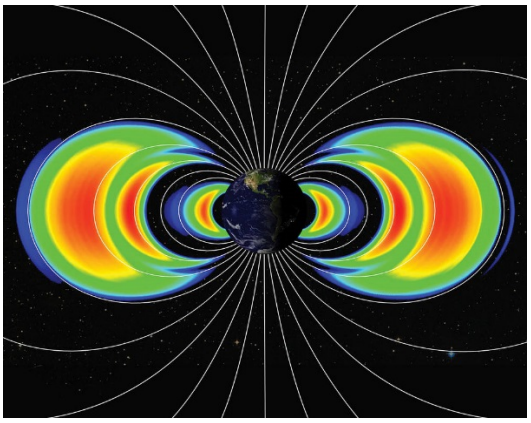
Earth's magnetic field (protects from damaging charged particles emanating from sun. (Credit: livescience.com)



Magnetic field around wire carrying a current (stackexchnage.com) Right hand rule gives the right sign of the force (stackexchnage.com)



Magnetic field generated by a solenoid (miniphyiscs.com)

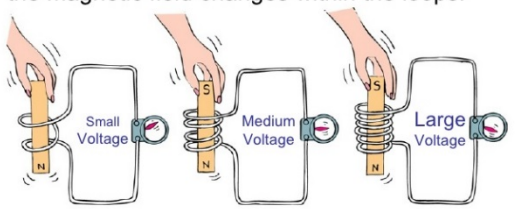


Van Allen radiation belts. Energetic charged particles travel along B lines

Electric currents (moving charges) generate magnetic fields but can magnetic fields generate electric currents. Answer (Faraday) YES. Moving magnetic fields can create electric currents. Duality between electricity and magnetism.

Faraday's Law

The induced voltage in a coil is proportional to the product of the number of loops and rate at which the magnetic field changes within the loops.

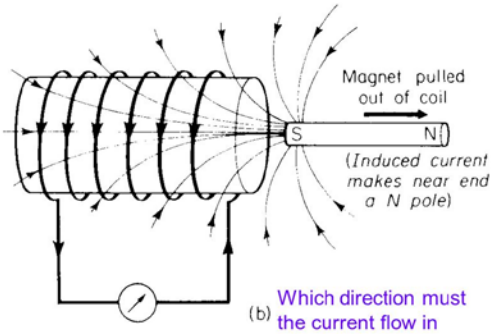


Magnetic force field must be moving. The sense is such that it would oppose the change.

Magnetic flux is the product of the magnetic field and the area.

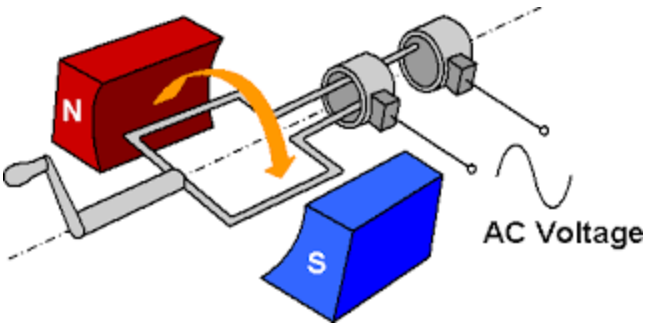
Changing flux generates the current.

Electromagnetic induction



(b) Which direction must the current flow in to make the near end north?

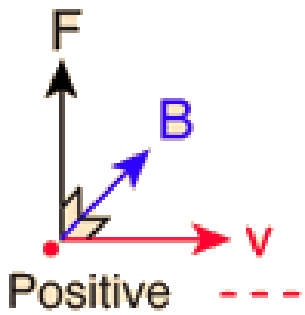
Note sense of current induced opposes changing magnetic flux.



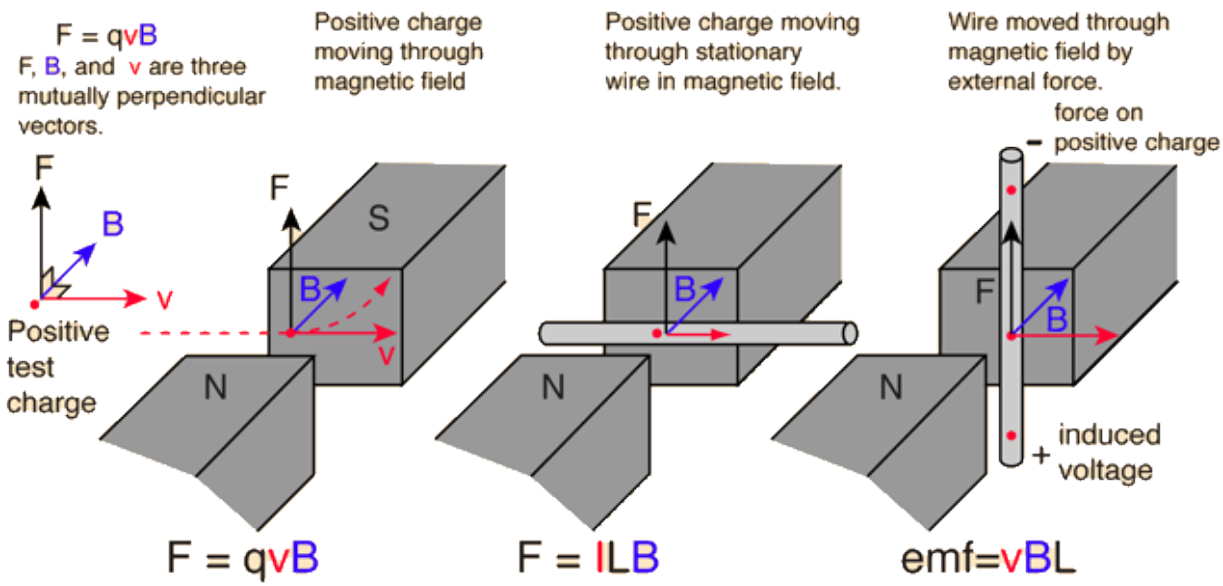
Generating electric currents
(macao.communications.museum)

Forces on wire carrying a current due to B field

$$\boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B}$$

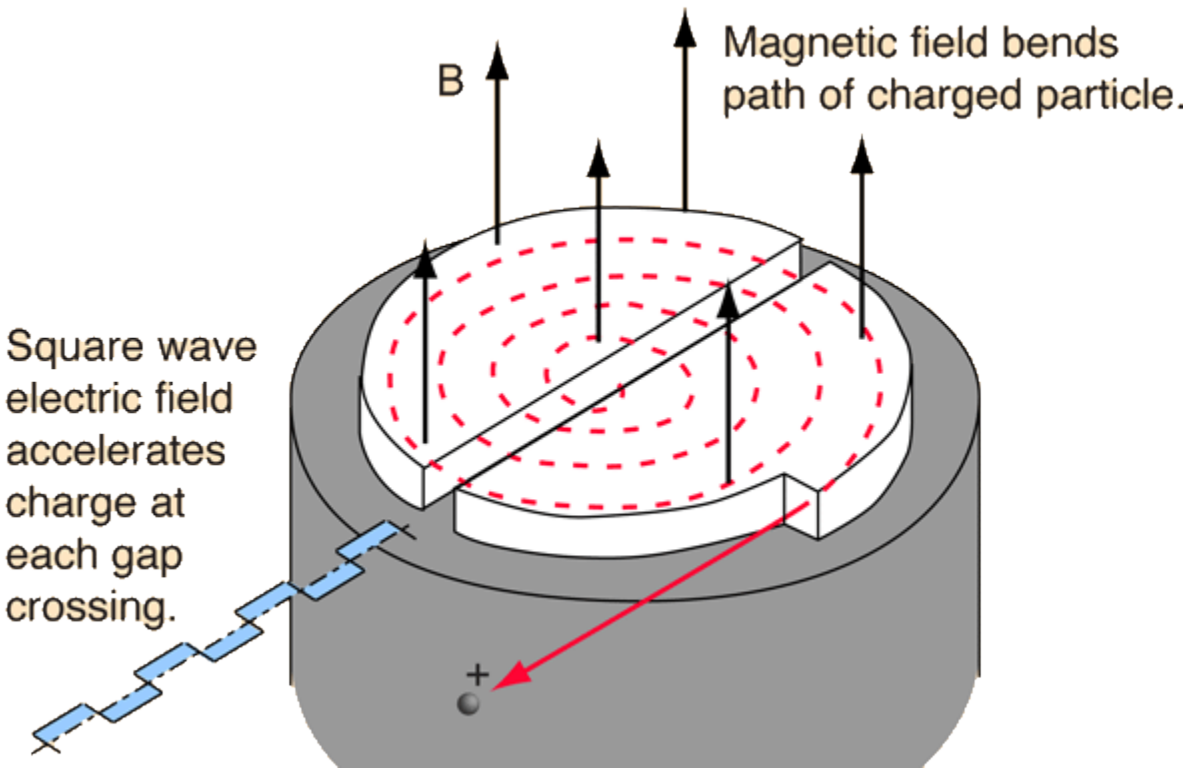


Right hand rule: rotate v to B and F is in direction of RH screw



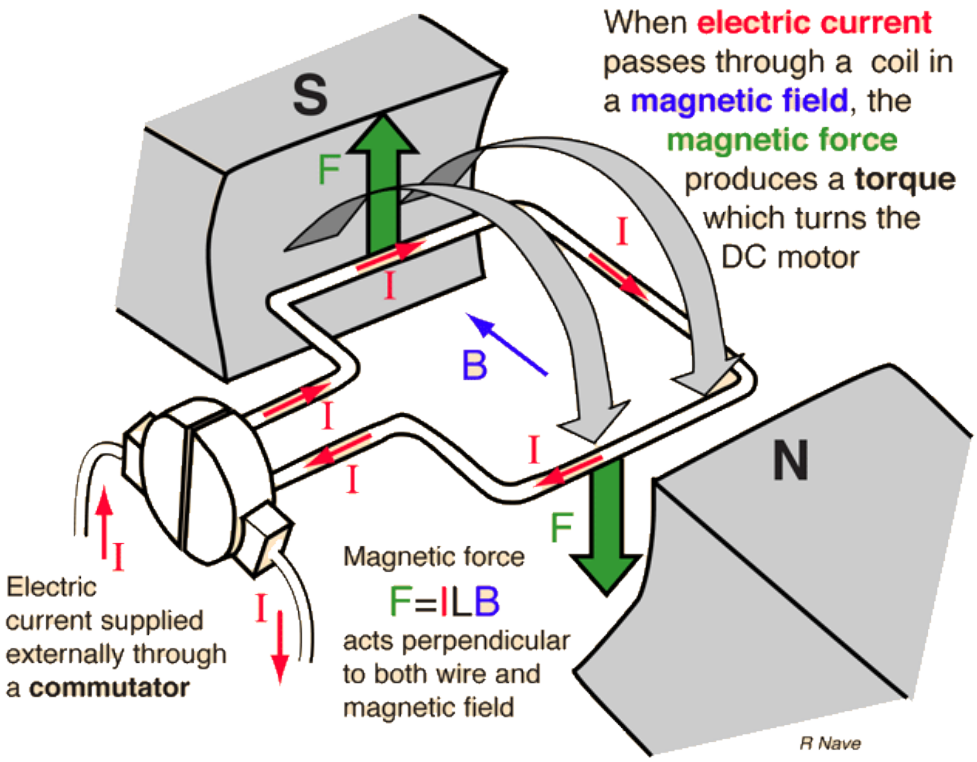
Credit: http://hyperphysics.phy-astr.gsu.edu

Cyclotron



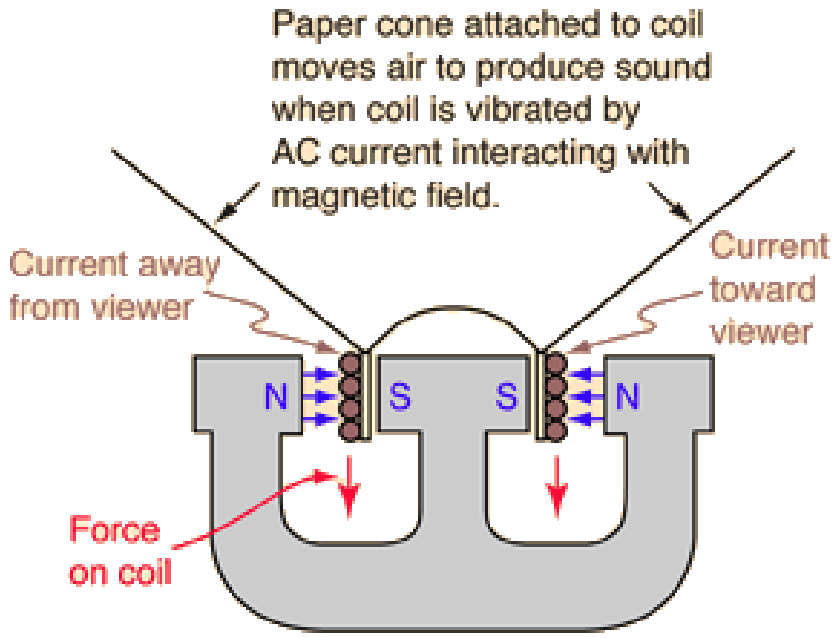
Credit: http://hyperphysics.phy-astr.gsu.edu

DC Motor



Credit: http://hyperphysics.phy-astr.gsu.edu

Loud

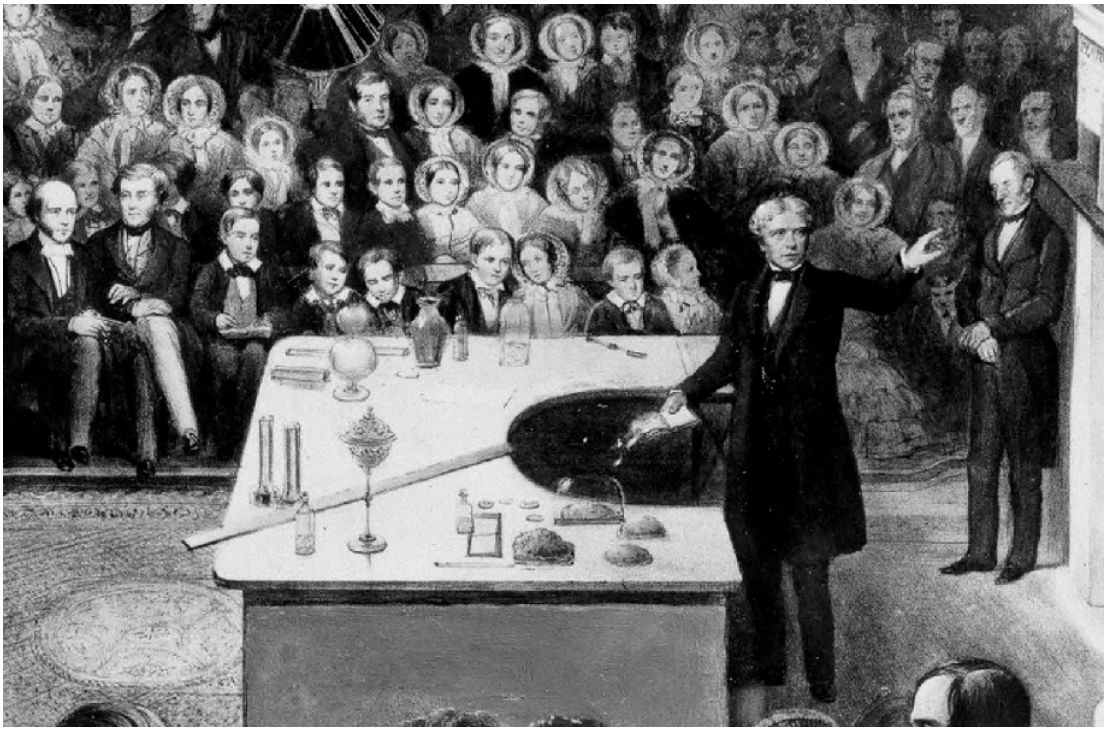


speaker

Giant Figure in Magnetism

Michael Faraday (1791-1867), humble origins, no math training but developed concept of force fields, became assistant to Humphrey Davies and later senior position at Royal Institution famous for lectures to nobility. Declined the offer of a knighthood. (Picture by Thomas Phillips, 1842.)

Christmas lecture at the Royal Institution (1856)

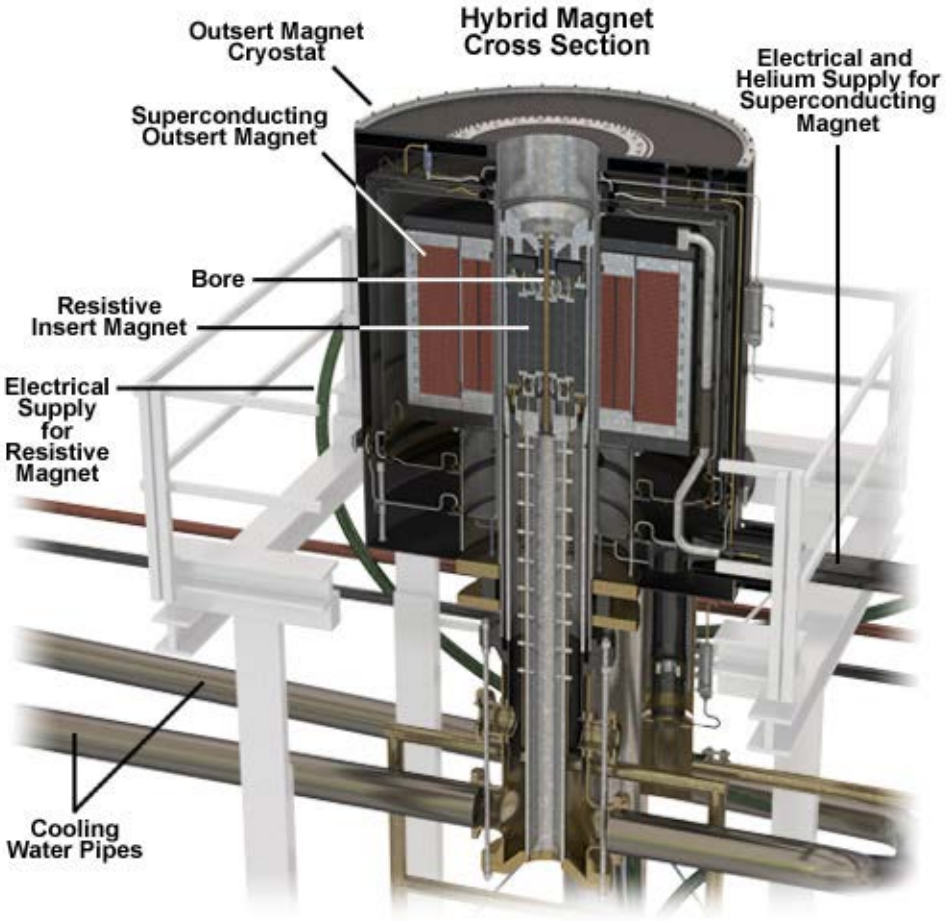


I am no poet, but if you think for yourselves, as I proceed, the facts will form a poem in your minds.

Why, sir, there is every probability that you will soon be able to tax it.

- Faraday's purported reply to William Gladstone, then British Chancellor of the Exchequer (minister of finance), when asked of the practical value of electricity (1850) as quoted in *Democracy and Liberty* (1899) by William Edward Hartpole Lecky, p. xxxi , and in *Discovery Or The Spirit And Service Of Science* (1918) by R.A Gregory, p 3.

World's most powerful DC magnet



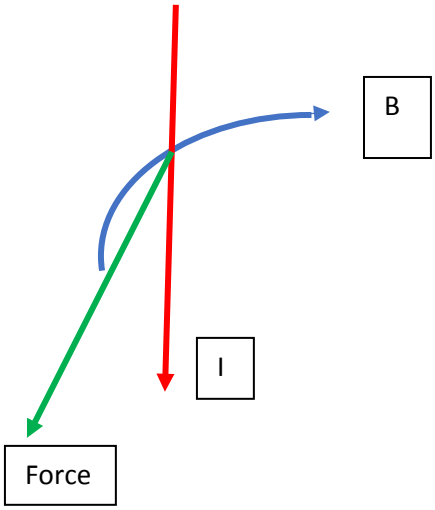
Outer 11.5 T superconducting magnet

Inner powered magnet 33.5 T.

30 MW Costs $1500/hour to run 4000 gals/min cooling water

35 ton 22 ft high Cost $M14.5 to build (1999)

Homopolar Motor (next experiment)



https://video.search.yahoo.com/yhs/search?fr=yhs-btbar-002&hsimp=yhs-002&hspart=btbar&p=homopolar+motor#id=51&vid=78f33791031013a2dfd9fa64ef010b67&action=click

https://www.instructables.com/id/How-to-make-a-Homopolar-motor-1/

Light

Geometrical Optics

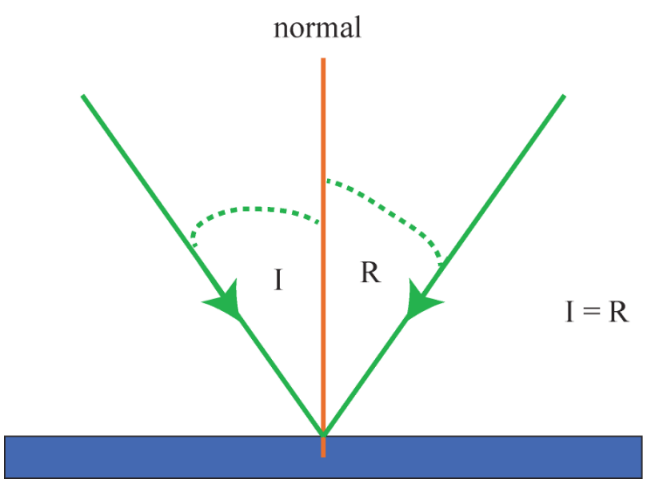
Newton treated light as corpuscular – a beam of particles (photons)

Huygens later showed light could be treated as waves – gave same results but can be more useful (interference effects)

Christiaan Huygens(1629 – 1695) was a Dutch physicist, mathematician, astronomer and inventor, who is widely regarded as one of the greatest scientists of all time and a major figure in the scientific revolution. In physics, Huygens made groundbreaking contributions in optics and mechanics, while as an astronomer he is chiefly known for his studies of the rings of Saturn and the discovery of its moon Titan. As an inventor, he improved the design of the telescope with the invention of the Huygenian eyepiece. His most famous invention, however, was the invention of the pendulum clock in 1656, which was a breakthrough in timekeeping and became the most accurate timekeeper for almost 300 years. Because he was the first to use mathematical formulae to describe the laws of physics, Huygens has been called the first theoretical physicist and the founder of mathematical physics.

Credit: Wikipedia, Painting by Caspar Netscher, Museum Boerhaave, Leiden

Laws of Reflection

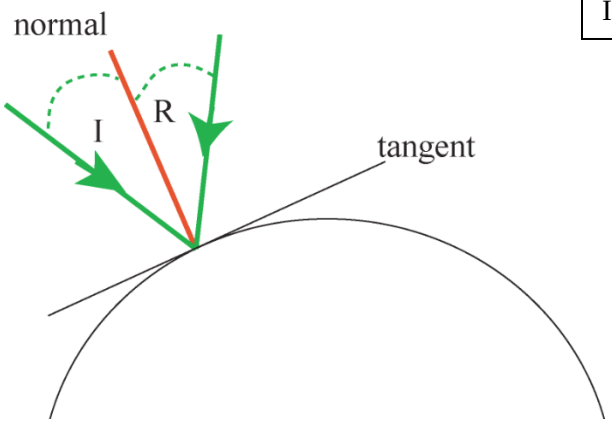


A ray of light is reflected such that

the angle of reflection = angle of incidence

Mirror surface

Curved surface



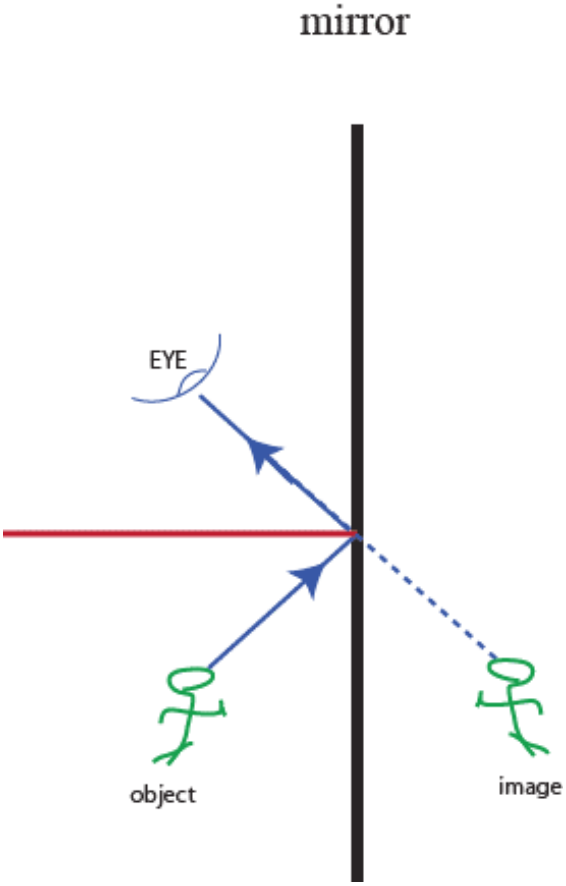
I= R

Applications

Plane mirror

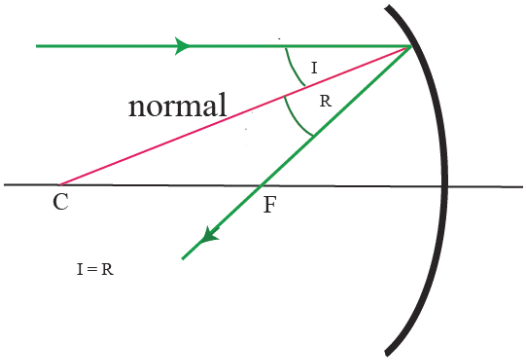
Image is behind mirror

(virtual image)



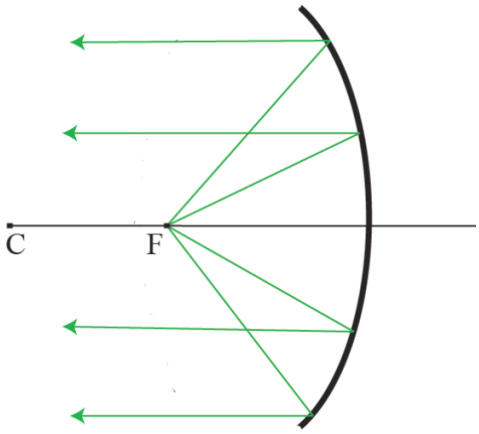
Spherical Mirror

Concave

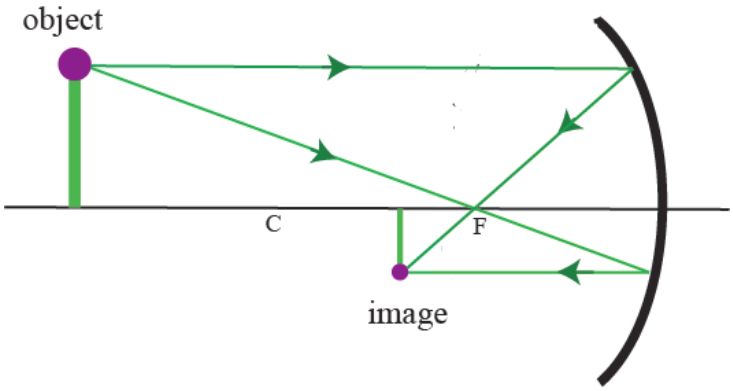


Parallel rays ALL go through the focus F

Rays from center C reflected back to C



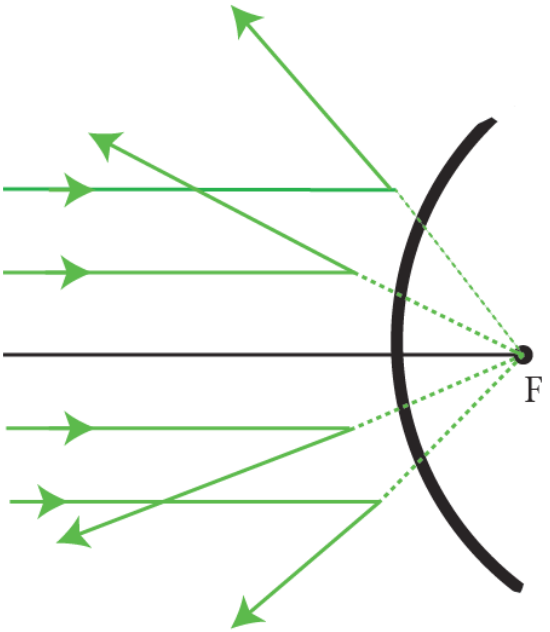
Source at focus F sends out a parallel beam from mirror



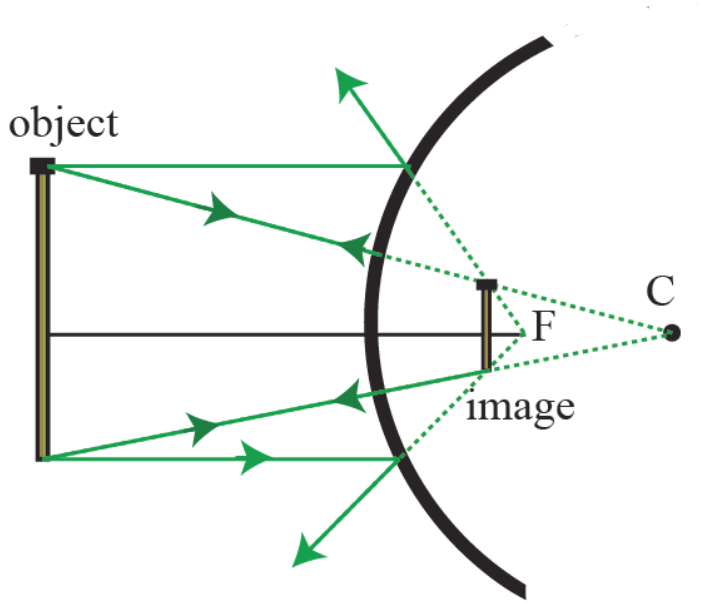
Object beyond C

Image inverted and reduced in size

Convex Mirror



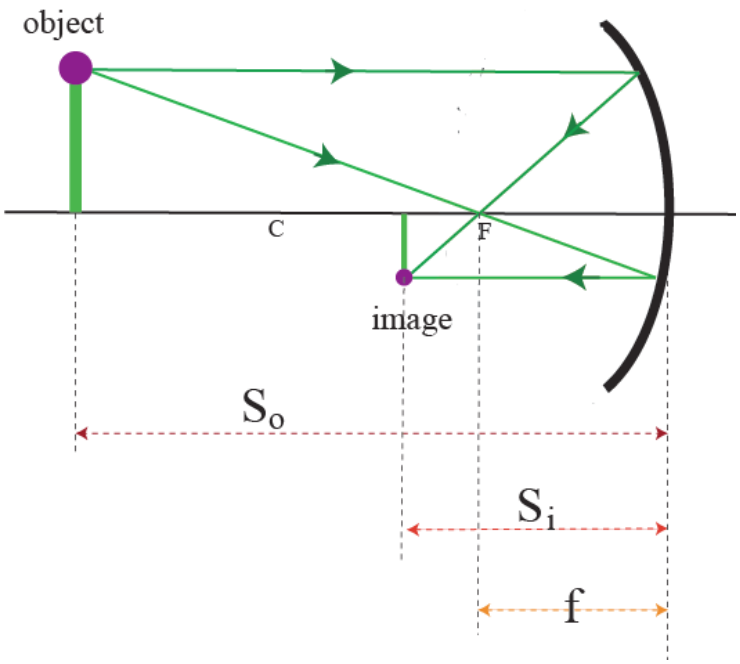
A parallel beam incident on convex mirror is reflected radially as if from a fixed point source at the focus point F.



Light from an object is emitted form a VIRTUAL image behind the mirror.

Image is upright and reduced in size.

The Mirror Formula (Concave)



$$\frac{1}{f} = \frac{1}{S_o} + \frac{1}{S_i}$$

Magnification $M = -\frac{S_i}{S_o}$

Example:

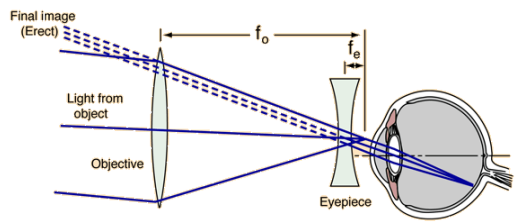
So = 30 cm, f = 10 cm

1/Si = 1/f - 1/So = 1/10 - 1/30 =2/30 or Si= 15 cm

M= - Si/So = - 0.5

Telescopes

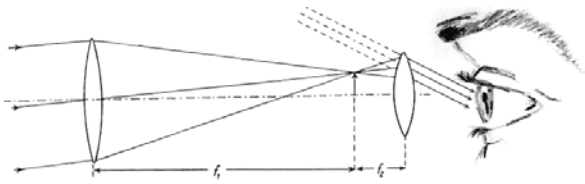
Galilean telescope



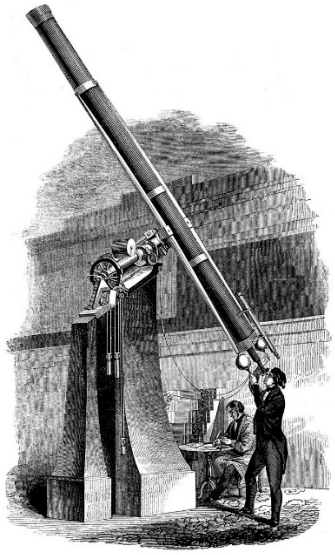
Galilean telescope uses a convex lens to focus parallel beam at a point, BUT intercept with concave lens just in front of image and this renders light parallel as it enters eye. Credit: Hyperphysics

http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/teles.html

Keplerian telescope

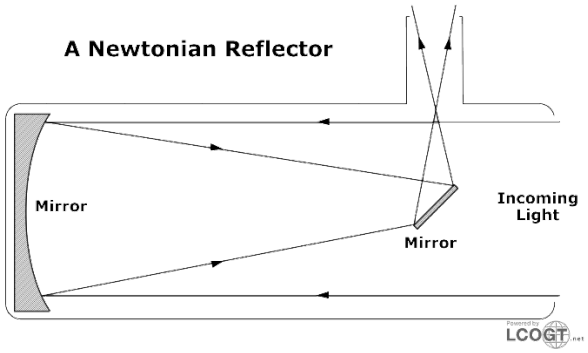


Uses convex lens for eyepiece. Needs to be very long. Image inverted. "Wider field of view & this Less eye strain" https://en.wikipedia.org/wiki/Refracting_telescope



By ... - Smith's Illustrated Astronomy, Designed for the use of the Public or Common Schools in the United States, Public Domain, https://commons.wikimedia.org/w/index.php?curid=20023550

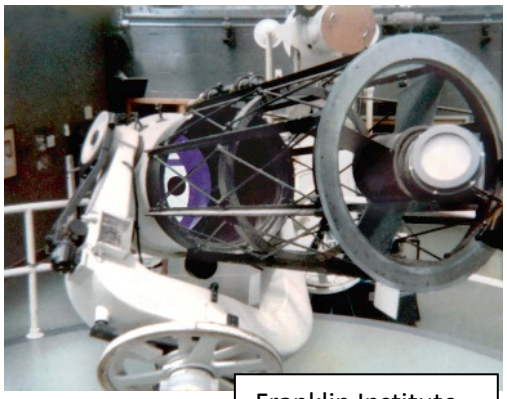
Reflecting telescopes



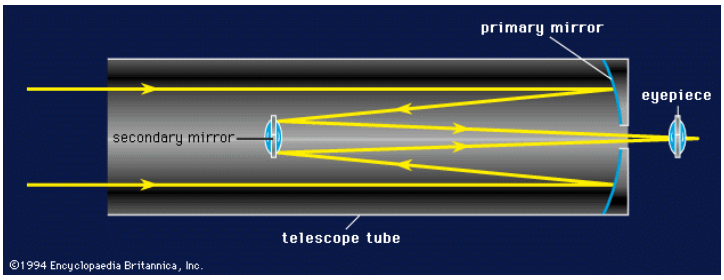
Use concave mirror to focus parallel beam (form far object) at focus, but intercept with mirror that's end to eyepiece. Light weak. Need LARGE area.

https://en.wikipedia.org/wiki/Reflecting_telescope

Mirrors advantage over Galilean refracting telescope. No chromatic aberration



Franklin Institute

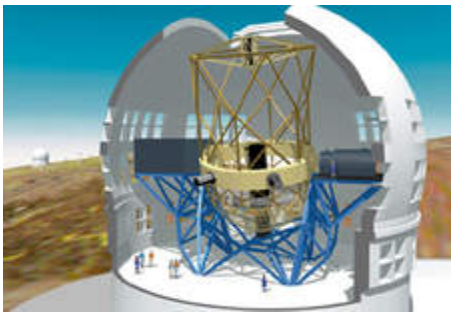


Cassegrain telescope sacrifice small area in center of concave mirror to exit image.
http://abyss.uoregon.edu/~js/glossary/reflecting_telescope.html

UF partner in Gran Telescopi Canaria

The GTC Project is a partnership formed by several institutions from Spain and Mexico, the University of Florida, the National Autonomous University of Mexico. It is the world's largest single-aperture optical telescope.[5] The division of telescope time reflects the structure of its financing: 90% Spain, 5% Mexico and 5% the University of Florida. (https://en.wikipedia.org/wiki/Gran_Telescopio_Canarias)

One of the most advanced optical and infra-red telescopes in the world. Its primary mirror consists of 36 individual hexagonal segments that together act as a single mirror. The light collecting mirror surface area of GTC is equivalent to that of a telescope with a 10.4m diameter single monolithic mirror. Thanks to its huge collecting area and advanced engineering the GTC classes amongst the best performing telescopes for astronomical research. (http://www.gtc.iac.es/gtc/gtc.php)

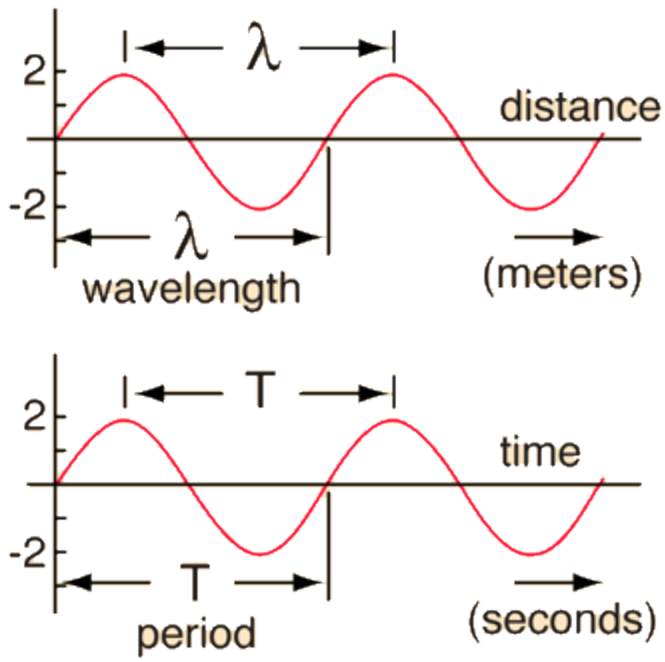


Wave motion

Many simple repetitive actions: motion of pendulum, bobbing of spring, waves in the sea … are described as waves and in simplest form given by a sine wave

A (amplitude) =C sin($2\pi t/T$) if repetitive in time: T is period, or frequency f=1/T

A= C sin ($2\pi x/\lambda$) repetitive in space. λ is wavelength



Moves with velocity V = $f\lambda$ m/s

Transverse waves. Amplitude of motion is perpendicular to direction wave is moving.

The wave advances one wavelength λ while the float executes one period T. The relationship

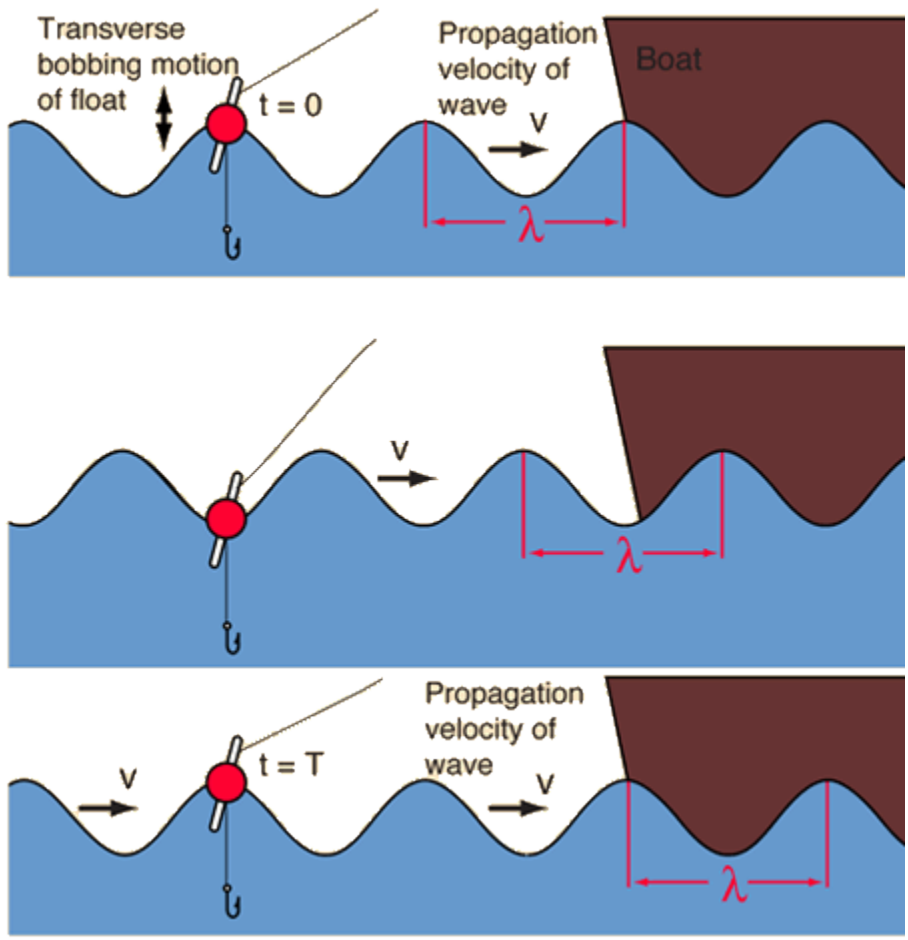
$$\lambda = vT$$

along with

$$T = 1/f$$

gives the usual form of the wave relationship

$$v = f\lambda$$

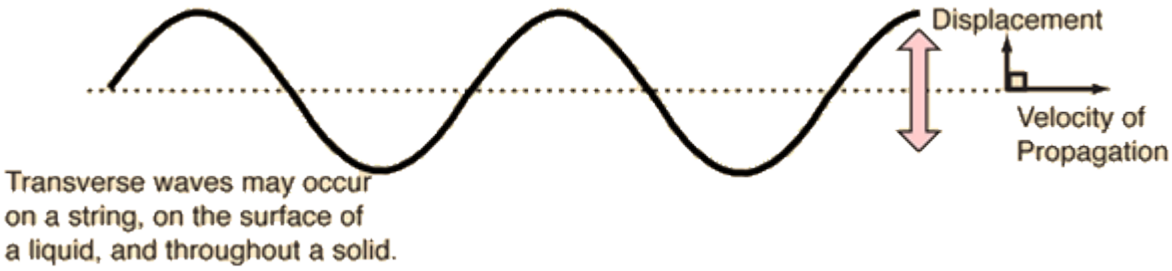


Travelling waves

Drop pebble in pond. Waves travel outward

Transverse Waves

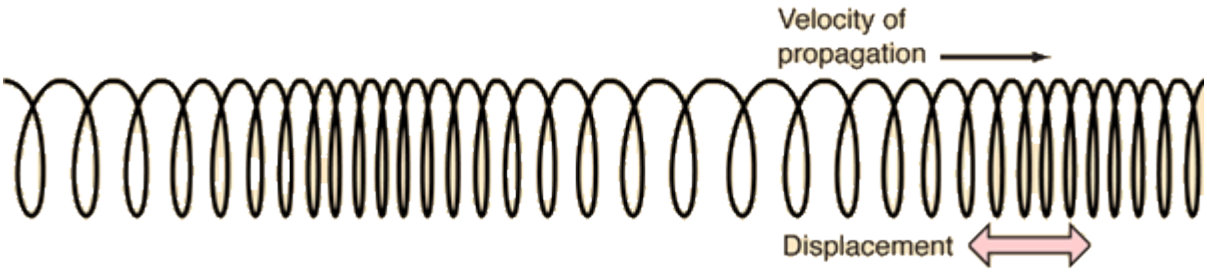
For transverse waves the displacement of the medium is perpendicular to the direction of propagation of the wave. A ripple on a pond and a wave on a string are easily visualized transverse waves.

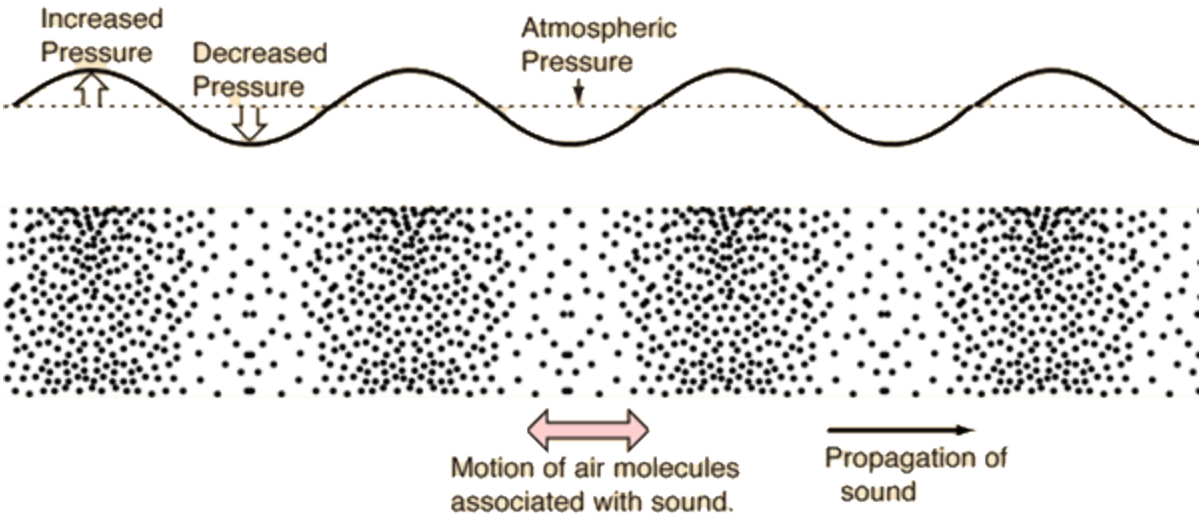


Transverse waves cannot propagate in a gas or a liquid because there is no mechanism for driving motion perpendicular to the propagation of the wave.

Longitudinal Waves

In longitudinal waves the displacement of the medium is parallel to the propagation of the wave. A wave in a "slinky" is a good visualization. Sound waves in air are longitudinal waves.

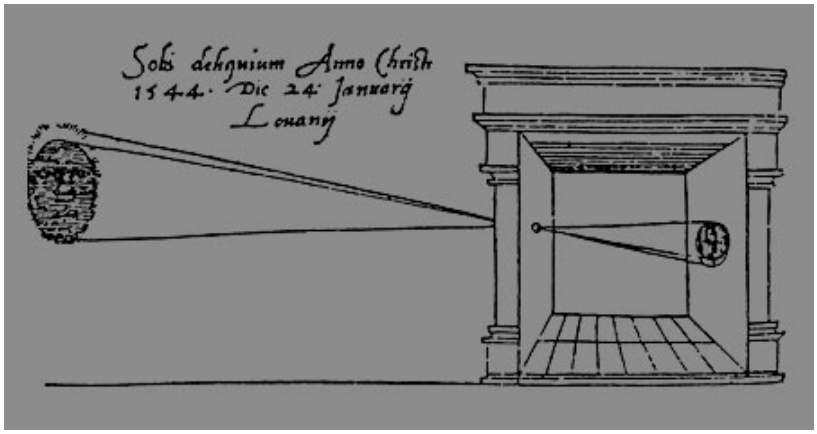



Increased Pressure
Decreased Pressure
Atmospheric Pressure
Motion of air molecules associated with sound.
Propagation of sound

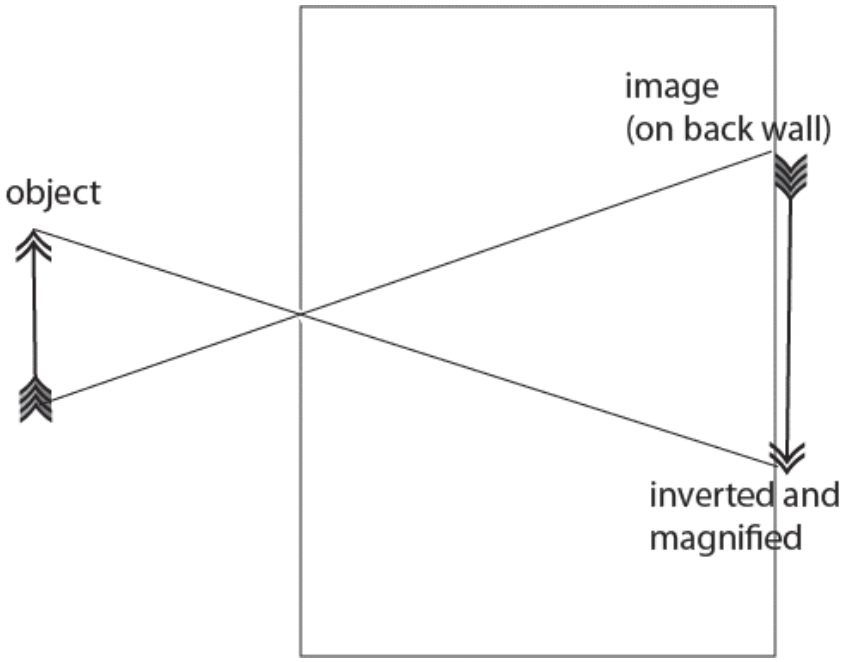
Pinhole Camera

“Camera Obscura”

Known to the Chines in 5th century. 10 AD, Arabian physicist and mathematician, Ibn al-Haitham, studied the reverse image formed by a tiny hole and indicated the rectilinear propagation of light. Also studied by Roger Bacon (1220-1292). First detailed description of the pinhole camera was set down by Italian artist and inventor Leonardo da Vinci, who used it to study perspective and published in *Codex atlanticus* (c. 1485).



Principle



Refraction

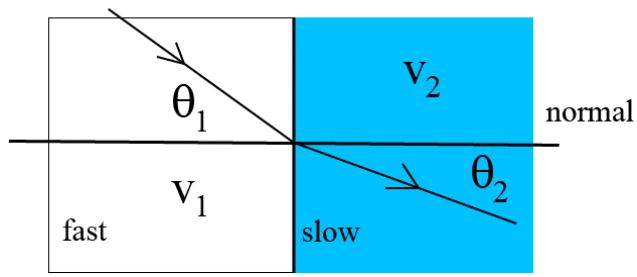
Speed of light v in transparent media different to vacuum, c.

Definition: Refractive index n= c/v

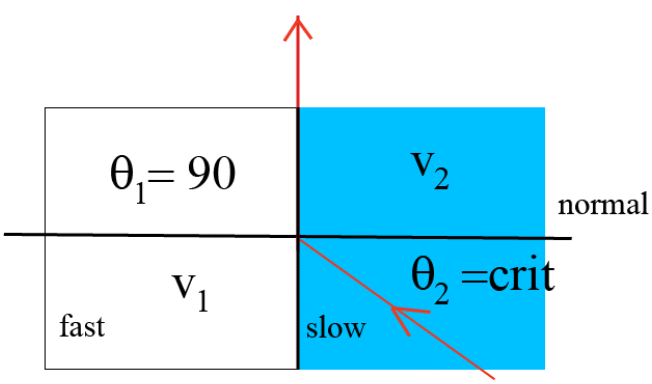
Result:

Snell's Law

$$\frac{sin\theta_1}{sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$



Material	n	Material	n
Vacuum	1.000	Ethyl alcohol	1.362
Air	1.000277	Glycerine	1.473
Water	4/3	Ice	1.31
Carbon disulfide	1.63	Polystyrene	1.59
Methylene iodide	1.74	Crown glass	1.50-1.62
Diamond	2.417	Flint glass	1.57-1.75

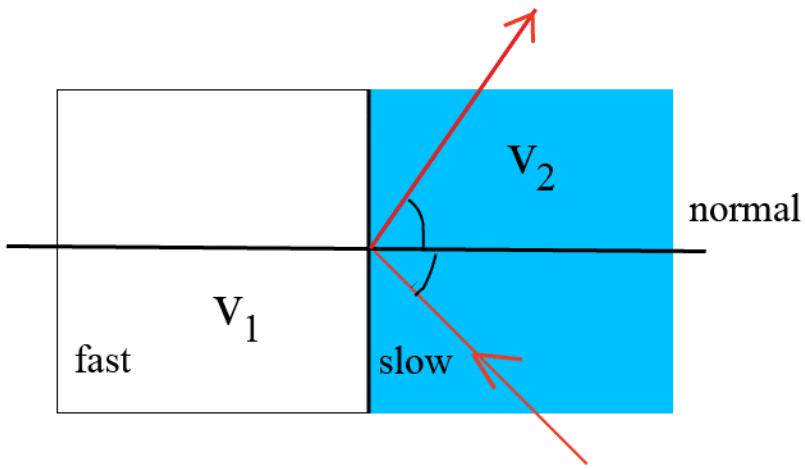


$$\sin\theta_{crit} = 1/n$$

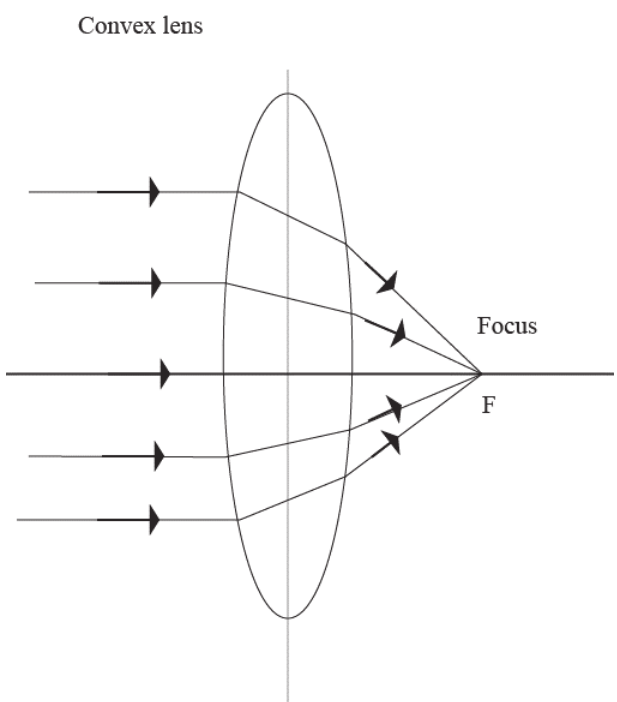
$$water\ n = 1.33$$

$$\theta crit = 48.6\ degrees$$

Total Internal Reflection



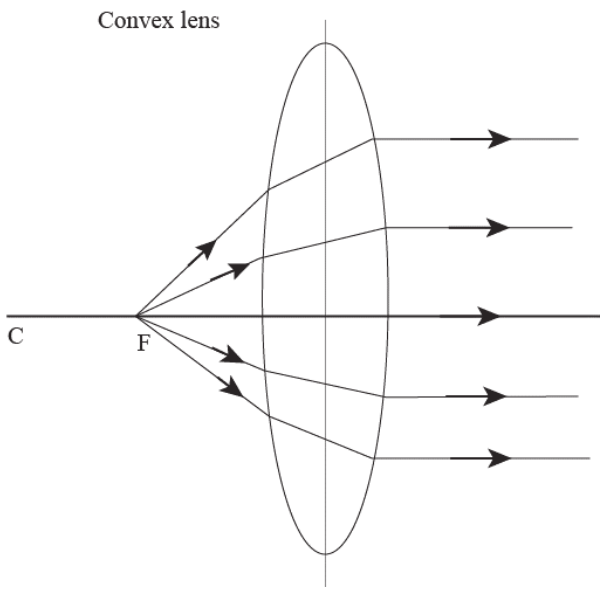
LENSES



Parallel beam is focused at focal point F.

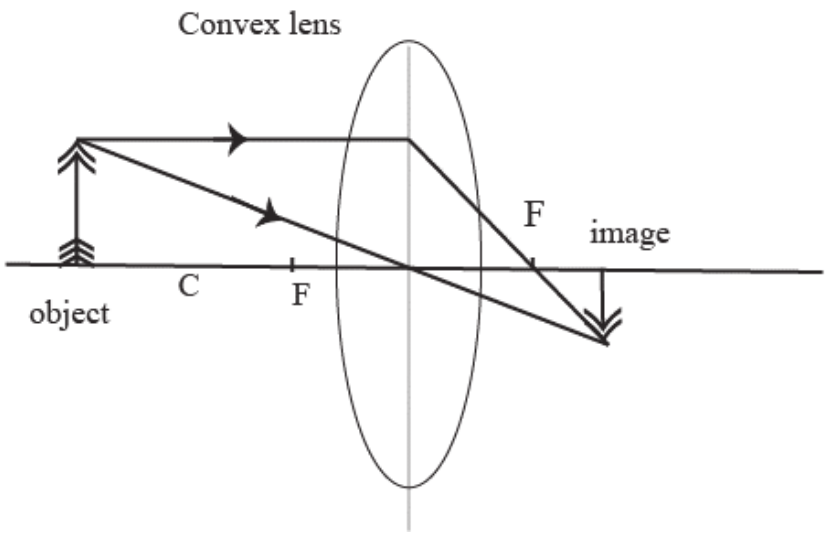
About half of distance to C

Center of curvature



Light source at F on side converted to parallel beam emitted on other side

Images of objects depends crucially on where the object is positioned



Object beyond C, image real, inverted and reduced

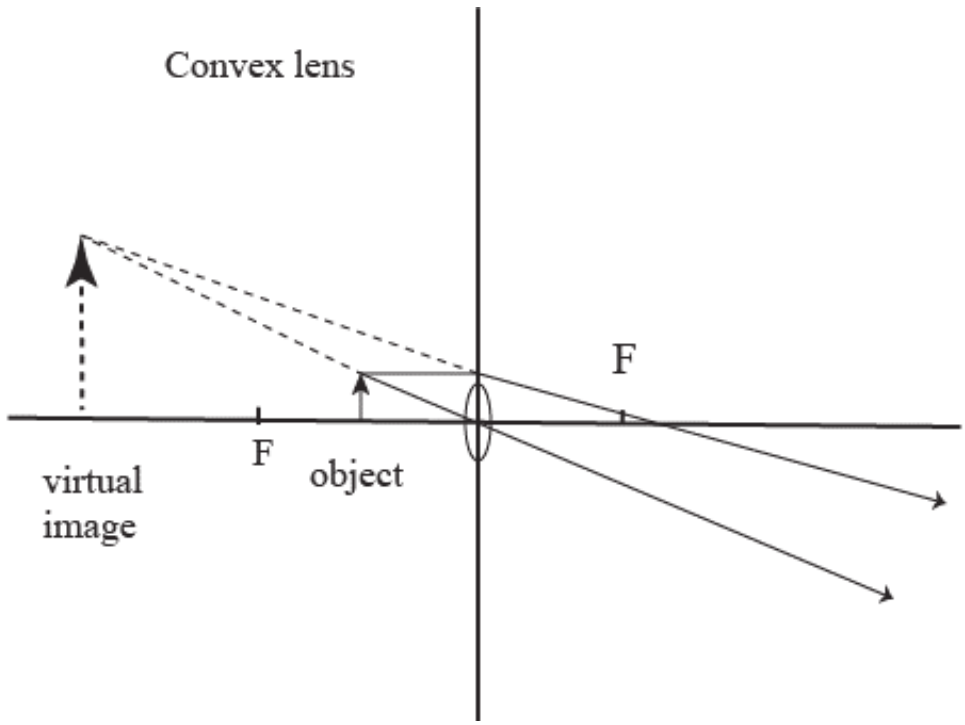


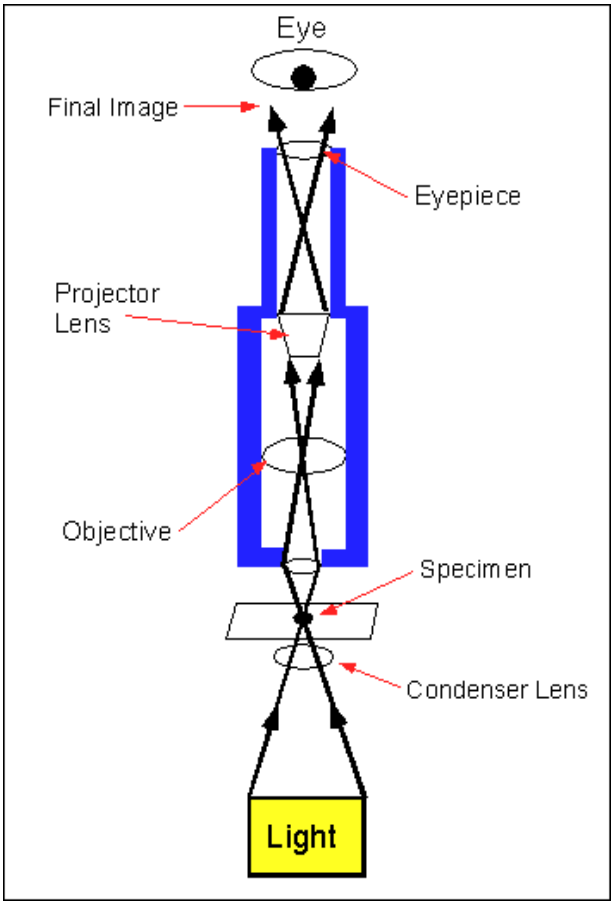
Image between F and lens, see virtual image and magnified (microscope)

Antonie van Leeuwenhoek (1632-1723)

Dutch tradesman and scientist

Simple lens achieved 250X
First to observe bacteria and protozoa.

https://www.britannica.com/biography/Antonie-van-Leeuwenhoek



Compound microscope

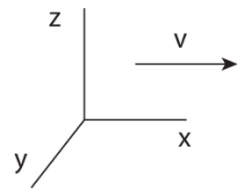
Multiple lenses can achieve 2000X

https://www.cas.miamioh.edu/mbi-ws/microscopes/compoundscope.html

Special Relativity

To measure motion need frame of reference.

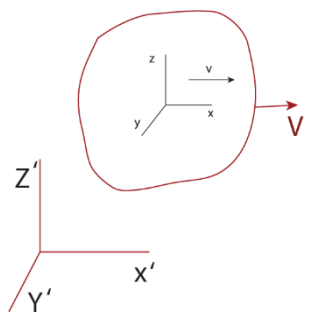
Velocity v measured in co-ordinate frame xyz.



But observer in another reference frame X'Y'Z'.

For which the first frame is moving at V will

measure v' = V+v (Galilean relativity). OK if v and V small)



Observations depend on frame of reference

e.g. rotation of Earth (east-West) 1600 km/h. relative to space observer

Plane traveling at 400 km/h will be seen moving at 2000 km/h.

Is there an absolute frame of reference?

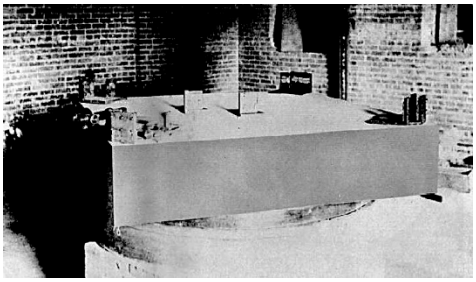
Early theories of electromagnetic waves postulated there was medium called the ether that supported the EM waves. Analogous to water supporting water waves.

The ether would provide an absolute reference frame.

Is there any experimental evidence for the ether?

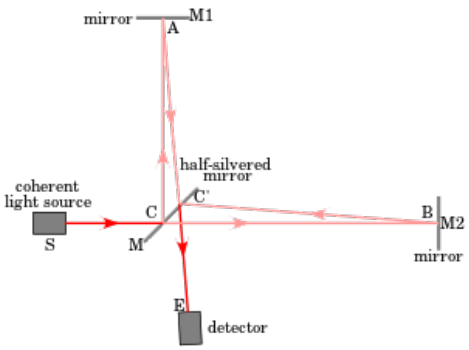
1887 Michelson and Morley tested the concept of the existence of an ether.

Measure the interference of light moving along different paths.



Experiment set up on massive sandstone slab floating in mercury to eliminate vibrations.

Credit: Case Western Reserve University - http://www.cellularuniverse.org/AA2MM_Aether.htm, Public Domain, https://commons.wikimedia.org/w/index.php?curid=48697725



https://en.wikipedia.org/wiki/Michelson_interferometer

Light travels along different but equal length paths and creates interference pattern. If motion along one arm (relative to ether) would see change in interference pattern.

NULL RESULT

Big puzzle… ether ??

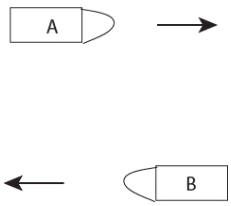
"Ad hoc" solution (not real theory) proposed by Lorentz, calculated by Lorentz,

Length of arm in direction of motion contracted by $\sqrt{1-\frac{v^2}{c^2}}$. c is velocity of light.

No real understanding. Mystery until 1905 Einstein paper (not clear if MM experiment influenced Einstein)

Einstein postulated c constant in ALL frames of reference, contrary to classical ideas of space and time

NO NEED for ETHER. ALL MOTION IS RELATIVE.



Rocket ships can only measure motion relative to one another.

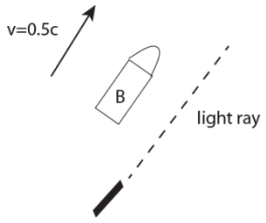
If sit in ship with no windows cannot determine if you are moving (if velocity is constant)

Einstein's Postulates

1. **All laws of nature same in all uniformly moving frames of reference.**
   In moving rocket ship if pour coffee, result same as if standing still.

   Einstein asked what if ran beside a light beam, but that would mean beam would seem at rest and light not propagating -- not possible.
   Concluded that not possible to pass c. Lead to 2nd postulate

2. **Speed of light in free space same value for all observers**



Person in rocket will measure c for light ray.

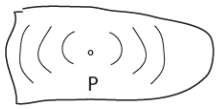
Simultaneity

Two events simultaneous if occur at same time

Observer at center of rocket ship

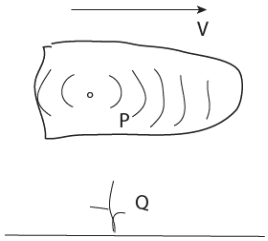
LIGHT PULSES EMITTED FROM THE CENTER

P SEES THE LIGHT REACHING EACH END SIMULTANOUSLY



OBSERVER Q, AT REST WITH RESPECT TO ROCKET SHIP, SEES LIGHT REACH BACK **BEFORE** IT REACHES FRONT (less distance to rear)

Q does not record simultaneity



Einstein's 3rd Postulate

Two events simultaneous in one frame of reference need not be simultaneous in frame moving with respect to the other frame.

Consequence of c= constant.

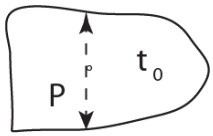
Space-time and Time Dilation

Location of point needs four co-ordinates: x, y, z, t.

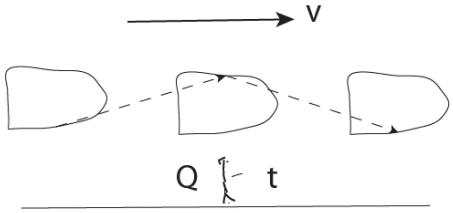
Look at distant galaxies looking back in time.

Two observers NOT in motion agree on measurements in space and time,

BUT, if in motion, will NOT agree (negligible effect at ordinary speeds but significant as approach c



For observer P inside rocket ship, light from center bounces back and forth from walls.



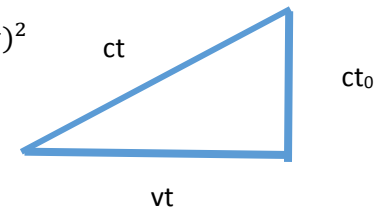
$$t = \frac{t_0}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}} > t_0$$

Observer Q on ground sees a different path. Flash appears to travel a longer distance but c is constant. Therefore flash of light seen by Q travels a larger distance and therefore longer time t.

TIME IS STRETCHED OUT

TIME DILATION

$(ct)^2 = (ct_0)^2 + (vt)^2$



Solve for t $\quad (c^2 - v^2)t^2 = c^2 t_0^2$ or $t^2 = \frac{c^2 t_0^2}{c^2 - v^2}$

$$t = \frac{t_0}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$

Lorentz factor

$$\gamma = \frac{1}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$

γ only appreciable for v near c

v=c/2 γ =1.15

Time dilation not an illusion – **real.**

Faster a clock moves the slower it appears to run viewed by an observer not moving.

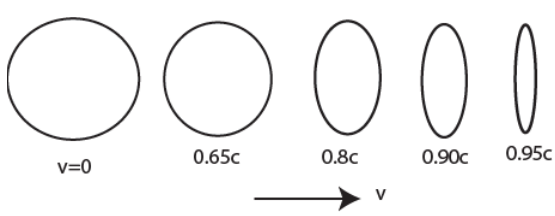
Well verified experimentally

Important for global positioning system (satellites moving with respect to us)

Length contraction

$$L = L_o \sqrt{(1 - \frac{v^2}{c^2})}$$

Space contracts. L =length of moving object



Length contracts in direction of motion

Another consequence: Momentum =γmv

E=mc^2 A small change in m releases huge energy