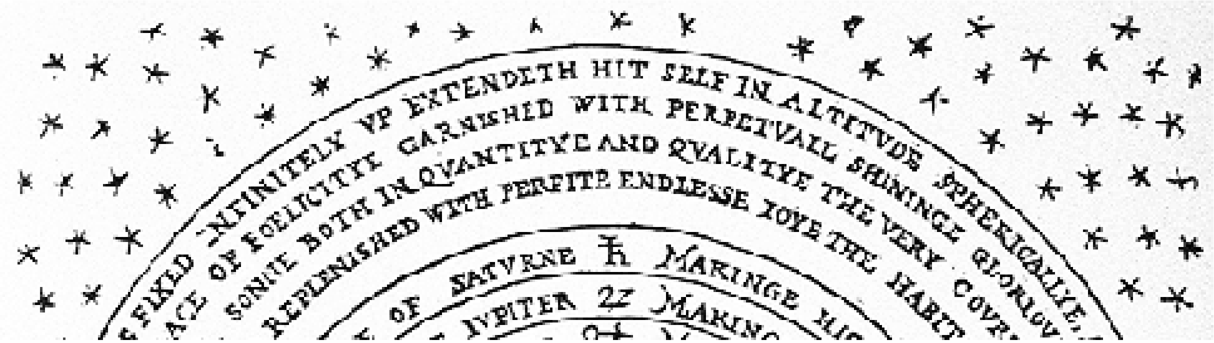


PHY1033C/HIS3931/IDH 3931 : Discovering Physics:

The Universe and Humanity's Place in It

Fall 2016

Prof. Peter Hirschfeld, Physics

Announcements

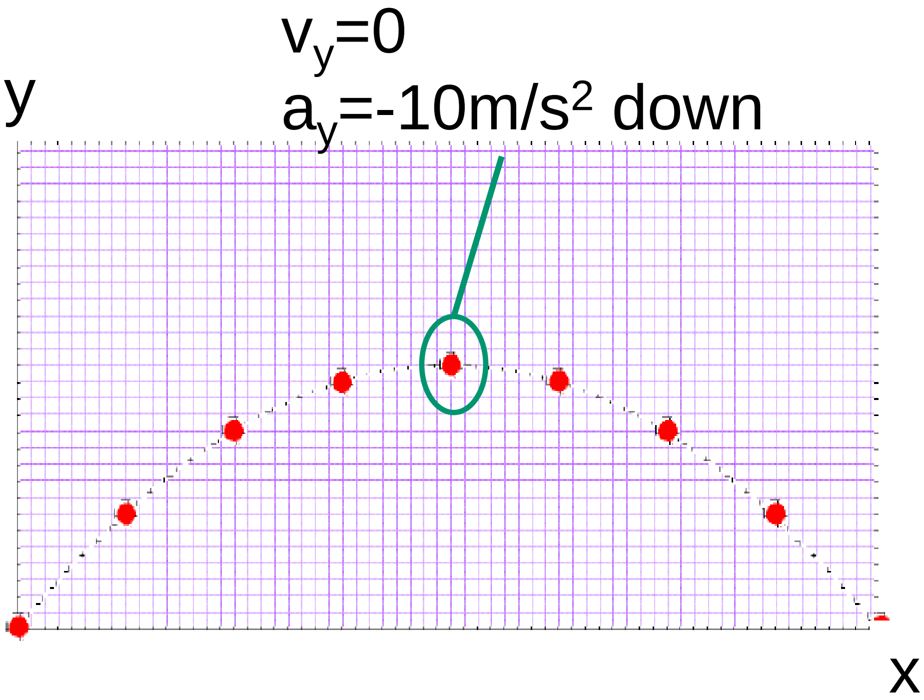
- HW 7 due today HW8 to be posted, due Nov. 8

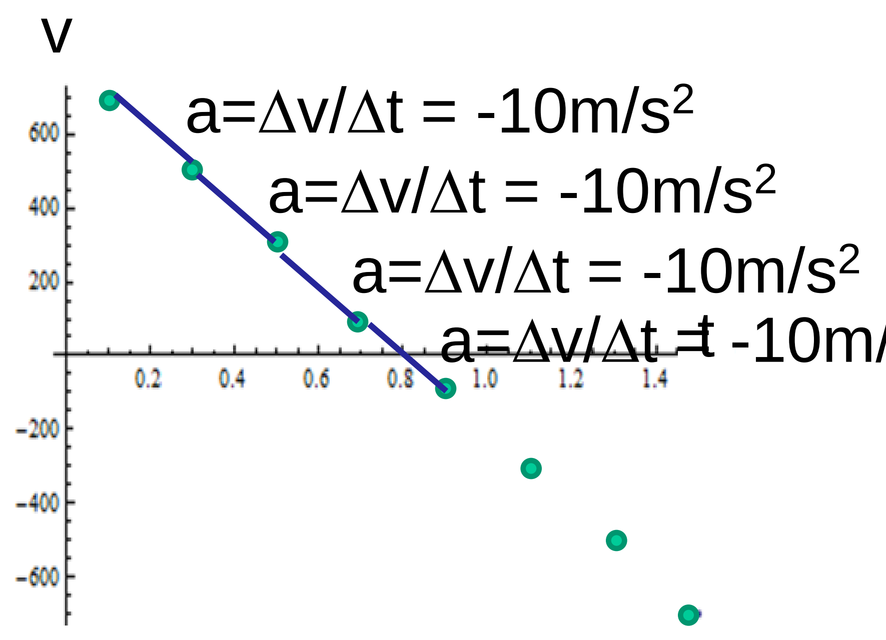
- Reading: Chapter 16, pp. 331-39; Chapter 20, pp. 411-18, 425-29, 431-33
Ronalds: *Francis Ronald's Electric Telegraph* (coursepack)

- Thurs., Nov. 10 4pm after class, NPB 2165:
  Optional film: Relativity pizza party!
  Or: other date/time?

- HW 6 remarks

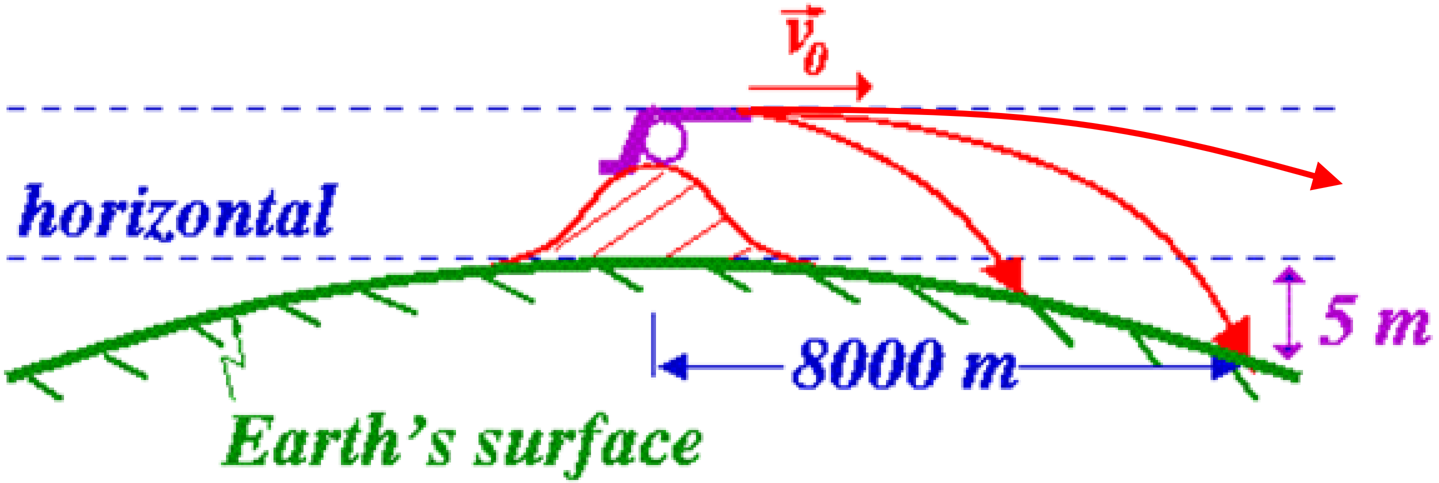
HW6 comments





At top of trajectory, v=0 but a=-10 m/s^2

Newton's cannon



- at surface cannonball falls $5\text{m} = \frac{1}{2}g(1\text{ s})^2$ below horizontal in 1st second of motion
- earth's curvature: surface falls away from horizontal by 5 m 8000 m away from you.
- Newton: If v_0 were 8000 m/s, drop caused by gravity would be matched by drop due to earth's curvature

  $\Rightarrow$ object never hits earth !

Last time

- **Momentum conservation**: every particle has its own mv (Descartes' "force of motion"). Sum of all all such momenta is conserved if there is no external force.
- **Energy conservation (1st law of thermodynamics)**: there is a quantity called energy which exists in various forms, but is always conserved, although its form can be changed.
- **Mechanical energy** consists of kinetic energy (Leibniz' *vis viva*), just ½ mv^2 per particle, plus potential energy (Helmholz's "tensive force") which depends on the position of the particle. For example, gravitational potential energy, mgh, depends on the particle's height h above the Earth's surface.

Momentum conservation

Q: What about Descarte’s original “force of motion” mv?
(v = velocity, has a sign or direction)

A: It’s conserved too!

Sir Isaac: $$F_{tot} = ma = m\frac{v_f - v_i}{t_f - t_i} = \frac{\Delta p}{\Delta t}$$

So if there is no total force applied to the system, the total momentum doesn’t change!

Mechanical energy

Def: *mechanical energy*: energy which is associated with the position or motion of macroscopic objects.

kinetic energy: energy of motion

$$KE = \frac{1}{2} m v^2$$

potential energy: energy of position, can take various forms.

The most common form is the gravitational potential energy an object has near the Earth's surface, when we can say

$$PE = m g h$$

where h is the object's height above the Earth’s surface

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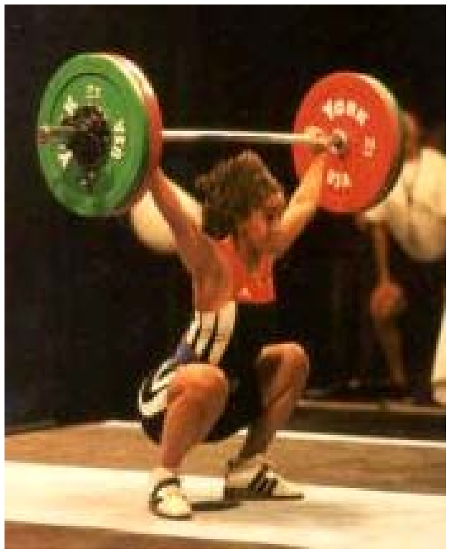
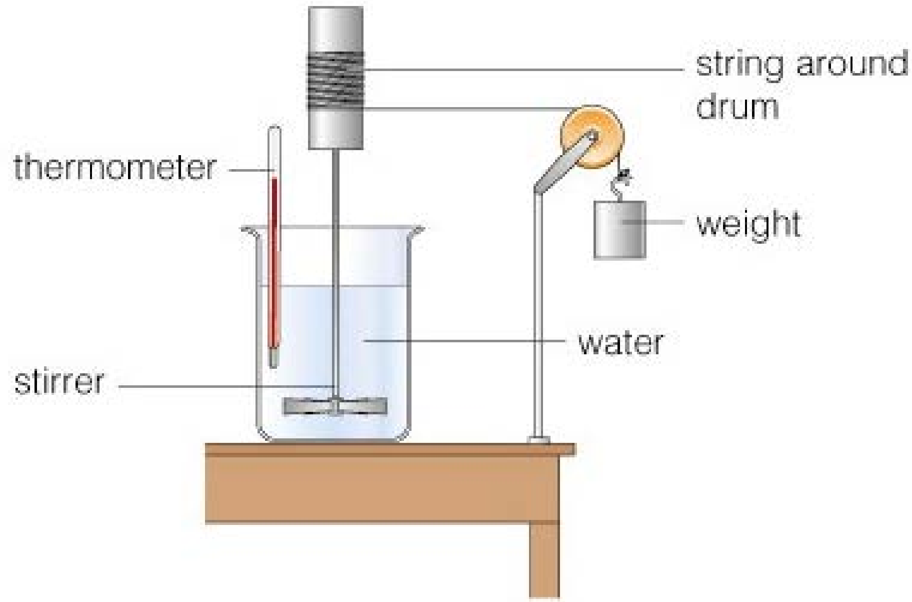
Work = *F·d* is energy supplied by an external force (James Joule)



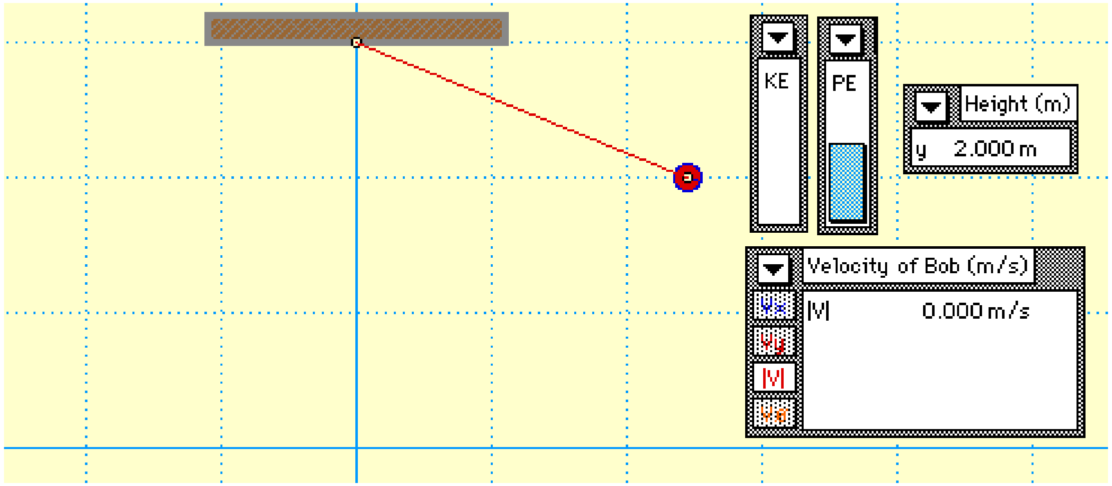


When we lift a barbell massing 50 kg a distance of 1 meter, we do work. If the barbell starts at rest and ends at rest, we have only changed its *potential energy* by *mgh,* i.e. 50 kg • 9.8 m/s^2 • 1m = 490 J. That energy is available to do work on something else.

Conservation of Mechanical Energy

If no friction is present, and no external force does work on a system, the system obeys conservation of mechanical energy (KE+PE=*const*.).

Example: pendulum. In this case, PE=*mgh*. When you let pendulum go, it has maximum height and zero speed, so max. PE and no KE. At the bottom, PE is minimum and KE maximum. The sum KE+PE is always the same.



Q: what's wrong with this video?

Example: what's the velocity of a ball dropped from leaning tower when it hits the ground?

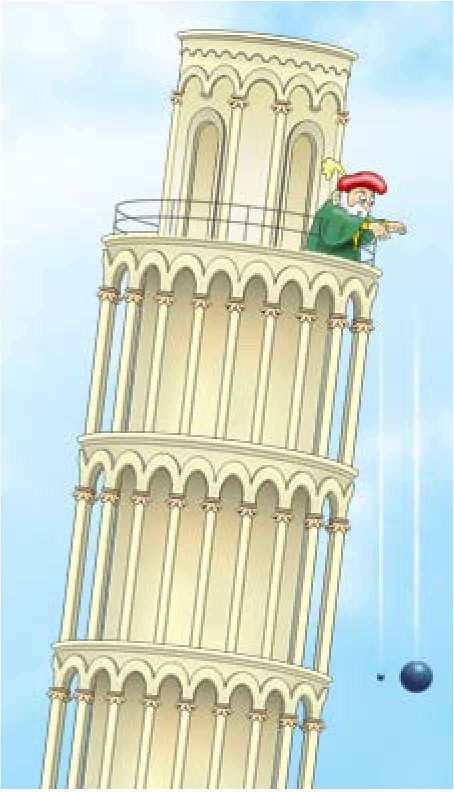
Old way:

$h= \frac{1}{2}gt^2$

$\Rightarrow t=\sqrt{(2h/g)}$

$v=gt= \sqrt{2gh}$

183m



Energy conservation:

before: E=PE+KE=mgh

after: E=PE+KE= $\frac{1}{2}mv^2$

$mgh=\frac{1}{2}mv^2$

$v=\sqrt{2gh}$

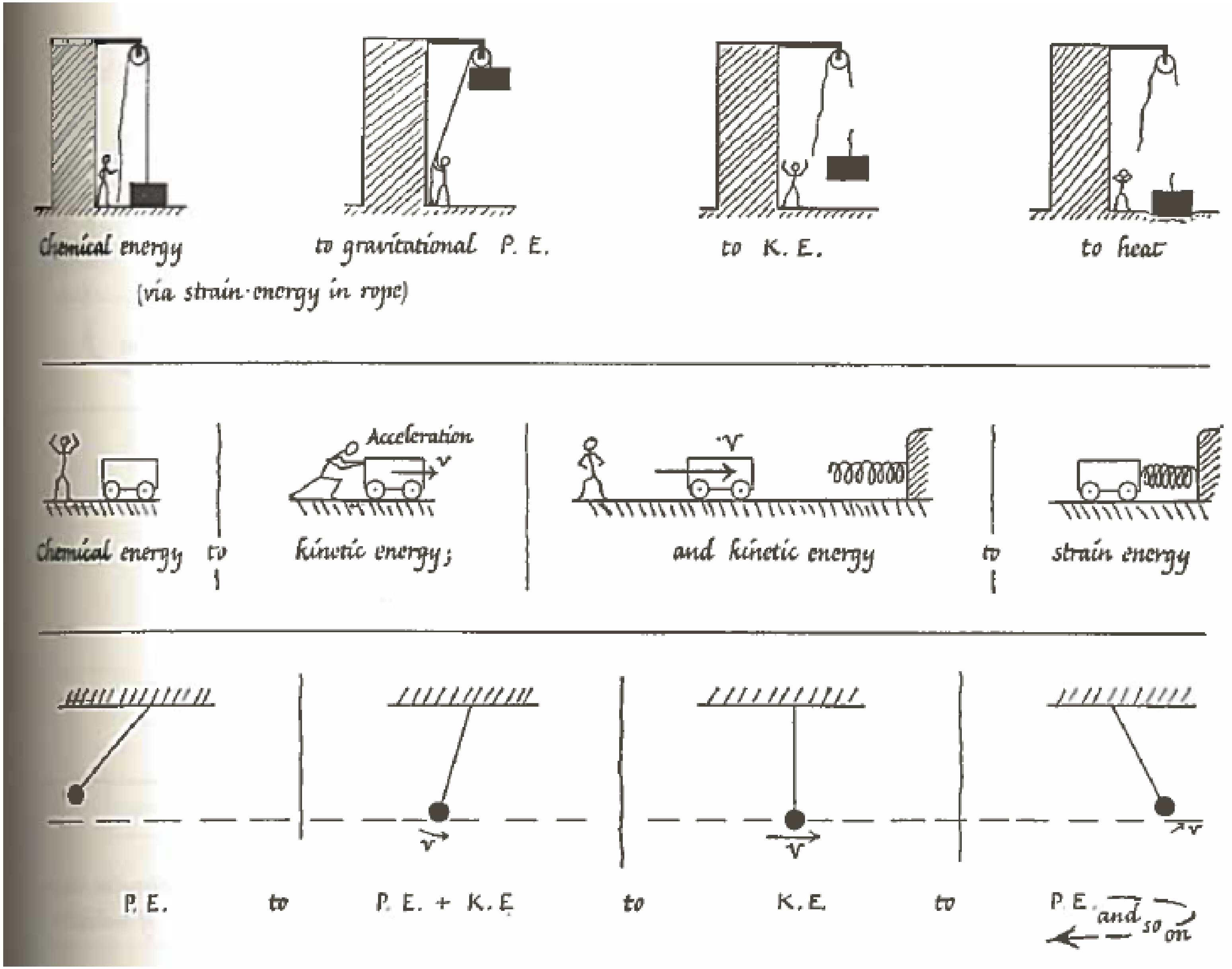
$v=\sqrt{2gh}=60$ m/s (down)

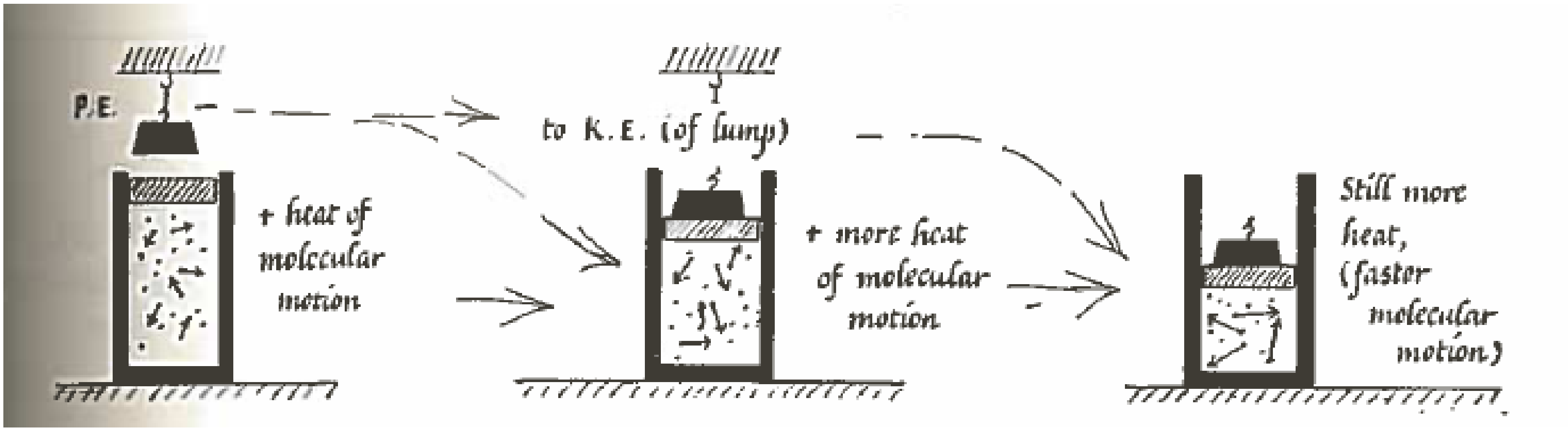
Kinds of energy

We normally think of many different kinds of energy:

- Chemical
  - Gasoline
  - Oil
  - Natural gas
  - Food
- Electrical
- Solar
- Geothermal
- Tides
- Nuclear

Different kinds of energy can be transformed, one into another




P.E.
to K.E. (of lump)
+ heat of molecular motion
+ more heat of molecular motion
Still more heat, (faster molecular motion)

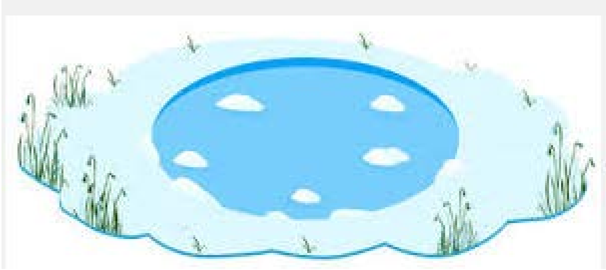
and so on…

1st law of thermodynamics

"Total energy is *conserved*, neither created nor destroyed"

NB: this is a fundamental principle of modern physics, *but* no one has *proven* that it is correct. We believe it because it has survived every experimental challenge for hundreds of years

There must be something else
(noted Carnot, Kelvin, Clausius…)



A pond on a hot summer day *never* freezes, giving up its heat to the air!

Q: Such a situation does not violate 1^{st} law of thermodynamics, yet it never happens. Why???

A: 2^{nd} law of thermodynamics: total entropy (disorder) always increases

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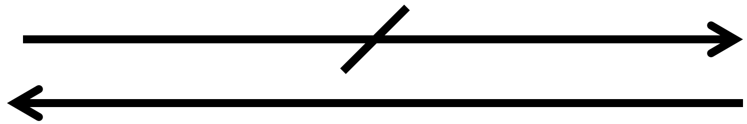

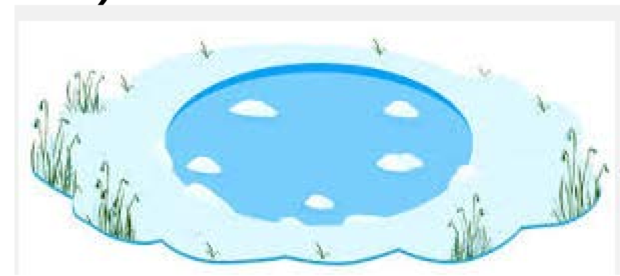

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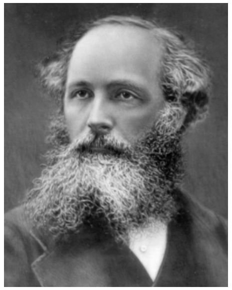
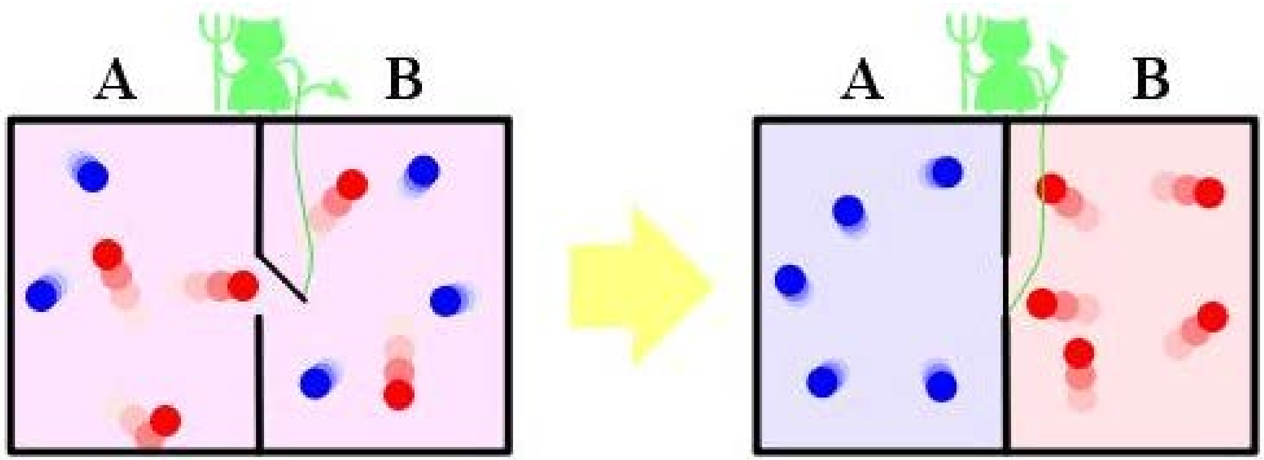
Note the 2nd law is only a *statistical* statement!



James Clerk Maxwell

Maxwell's Demon:

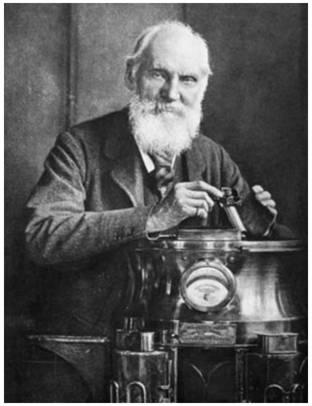


Entropy decreases!

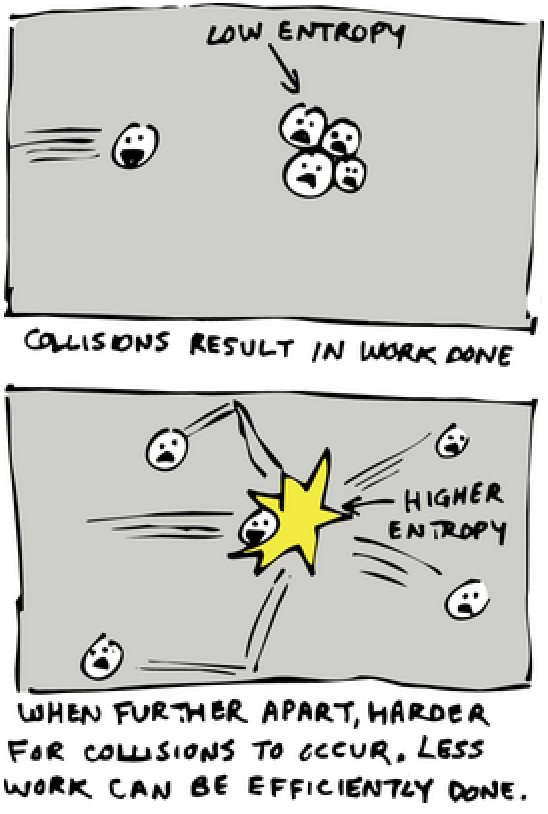
2nd law could be violated by a demon – except what is the increase in *his* entropy? Nature has no such demons!

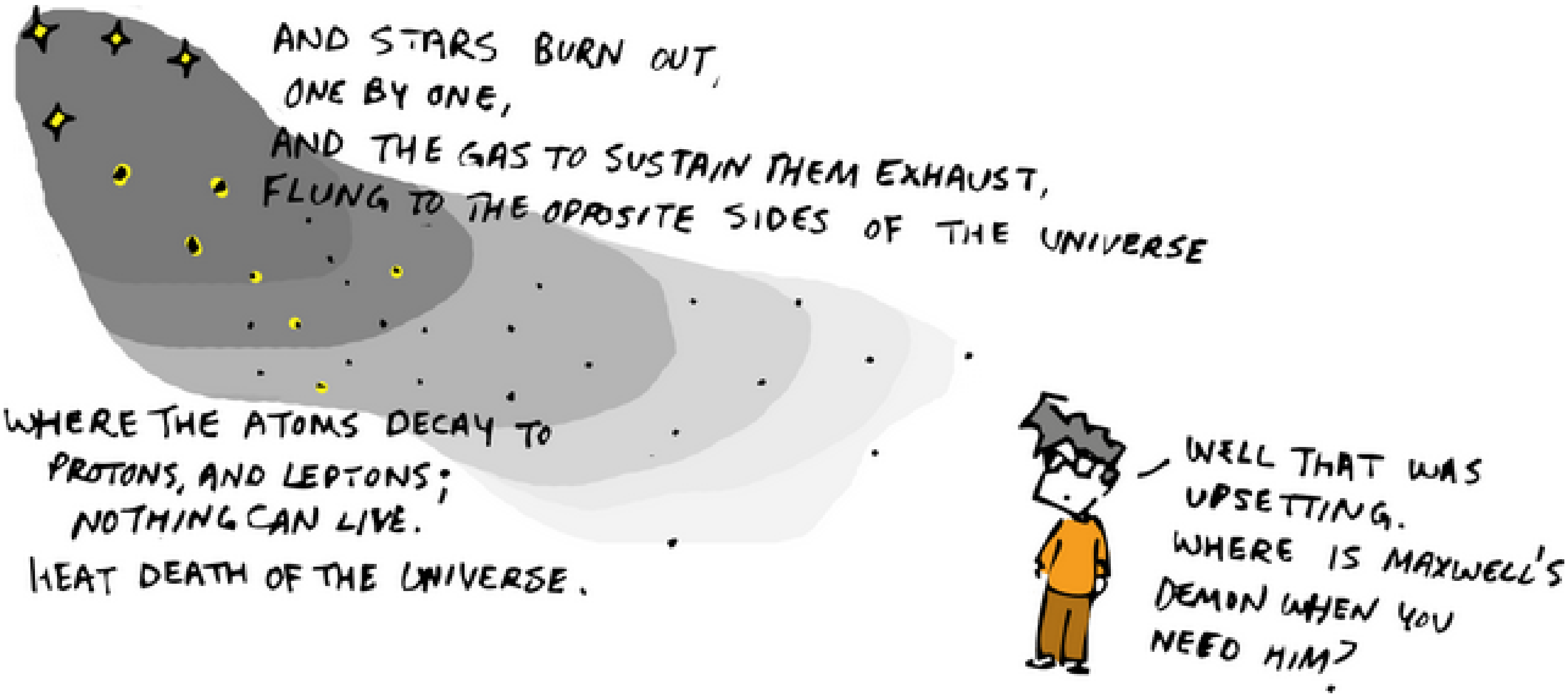
“Heat death” of the universe?

William Thompson, Lord Kelvin (1852)



Interactions of hot and cold bodies generally lead to equilibrium, coming to common temperature. If this continues indefinitely, universe will be at uniform temperature, no work can be done $\Rightarrow$ universe is “dead”



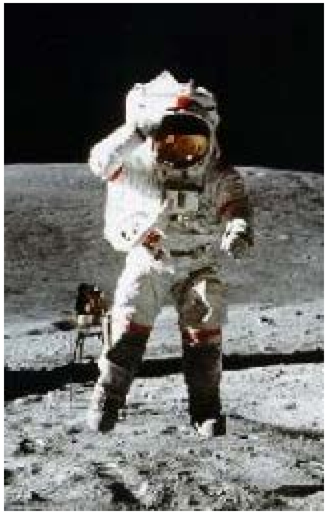


(…or Newton's God, who can wind up the universal clockwork again…)

Best estimate of time to heat death : 10^{100} years (wikipedia)

Clicker question

When the Apollo astronauts were on the moon, they did not fall off because

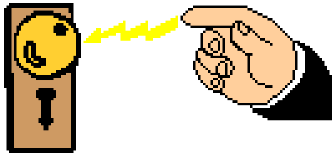


A) The Earth's gravity extends to the moon
B) They wore safety ropes
C) They had heavy boots
D) The moon has its own gravity
E) The moon is in orbit

Electricity and magnetism

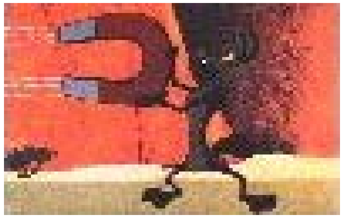
Where do you see electricity and magnetism in nature?

Rub a balloon or plastic rod, find they can attract or repel other objects, or stick to surfaces :
"static electricity" – what is it really?



Lightning is "electricity" – but what is it?

Bar magnet on refrigerator – why does it stick?



…and what, if anything, do these things have to do with each other?

The Greeks knew that if you rubbed a piece of amber you could pick up little pieces of papyrus. They knew about a kind of rock, later called lodestone, which would attract iron. And they had seen lightning. It took twenty centuries before an understanding of the *connections* among these effects came about, in France, Britain, and the United States.

In intellectual terms, relating such apparently diverse phenomena under one theory was comparable to Newton's idea that the force which attracted the apple to the earth and the earth to the moon were one and the same.

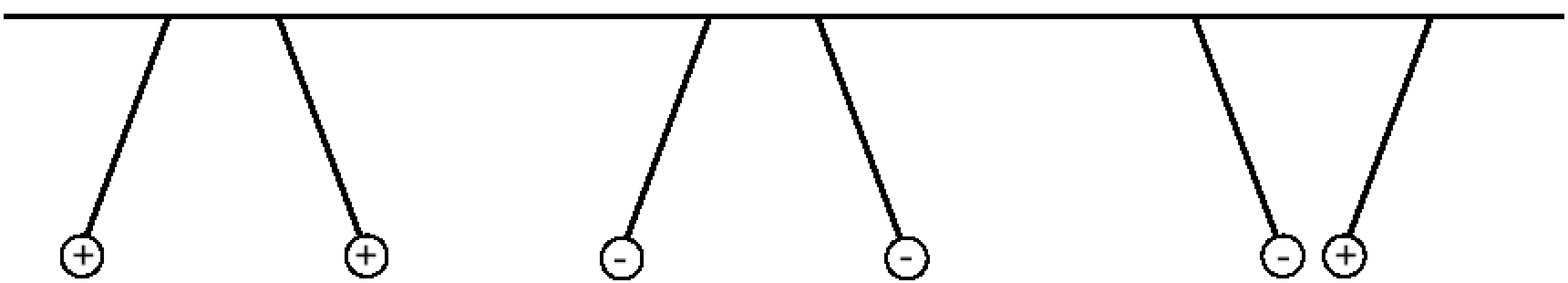
Two types of electrical *charge* (Franklin)

Charges are either *positive* or *negative*.

- **Electrons are negative**
- **Protons are positive**

Like charges repel

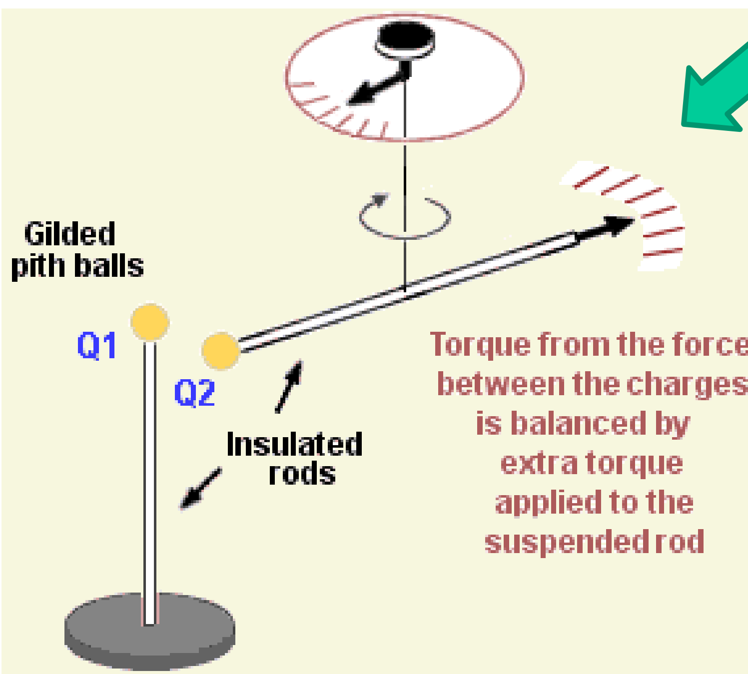
Opposite charges attract

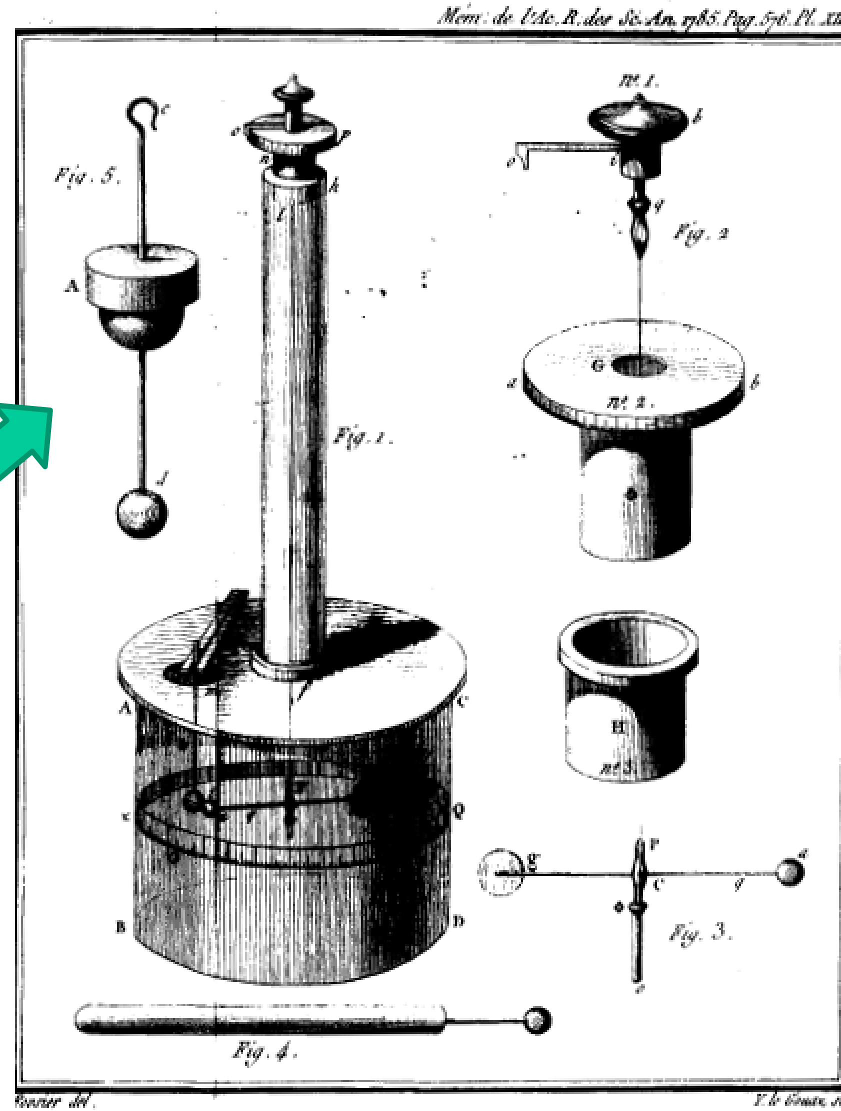


The unit of charge is the *Coulomb*

- **The charge on an electron is -1.6×10^{-19} C**
- **The charge on a proton is $+1.6 \times 10^{-19}$ C**

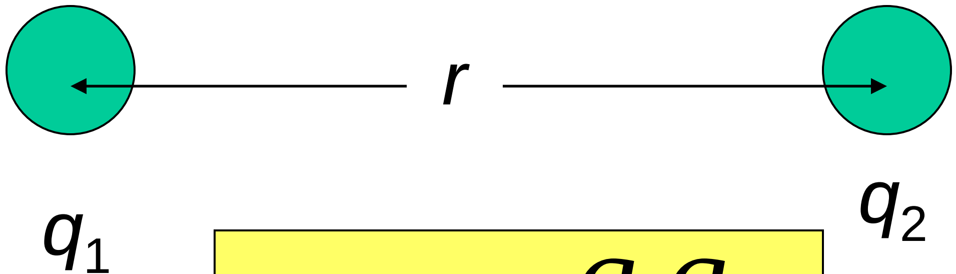
Charles Augustin de Coulomb (1736-1806)





Force between two point electric charges:

Coulomb's law (C. Coulomb, 17th cent.)



$$F = k\frac{q_1 q_2}{r^2}$$

where k=9x10^9 N m^2/C^2

Can be *repulsive* ($q_1\, q_2 > 0$) or *attractive* ($q_1\, q_2 < 0$)

Also: gravity is *incredibly weak* compared to EM force! (see HW!)

Q: if electric force is strong, F ~ $1/r^2$ why are effects so well hidden?

Effects of gravity are observed by us in star systems light years from us, yet effects of EM force are hard to find in our own back yard. Why?

A: Fundamental difference between gravity and EM force: gravity is only attractive, EM can be attractive *or* repulsive. Atoms are *neutral.*

History of magnetism

<u>800 B.C.</u> First Greek writings about "lodestone"

Lodestone-magnetic iron ore $FeO\text{-}Fe_2O_3$.
Name *magnet* comes either from origin in Greek province of *Magnesia,* or (Pliny) from name *Magnes* of shepherd "the nails of whose shoes and the tip of whose staff stuck fast in a magnetick field while he pastured his flocks."

<u>800 B.C.</u> - 0 A.D. Early theories of magnetism:

1) magnet "feeds on" iron;
2) magnet emits "effluvia"-invisible objects or fluid.

History of magnetism (cont’d)

- Diogenes of Apollonia (460 B.C.): Iron contains humidity which dryness of magnet feeds upon

- "First, from the magnet num'rous Parts arise.
And swiftly move; the Stone gives vast supplies;
Which, springing still in Constant Stream, displace
The Neighb'ring air and make an empty Space;
So when the Steel comes there, some Parts begin
To leap on through the void and enter in...
The Steel will move to seek the Stone' s embrace,
Or up or down, or t'any other place
Which way soever lies the empty Space.

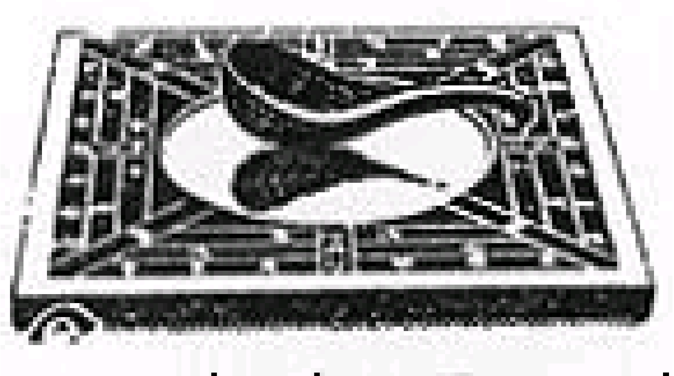
-Lucretius Carus, Roman poet.

History of magnetism (cont'd)

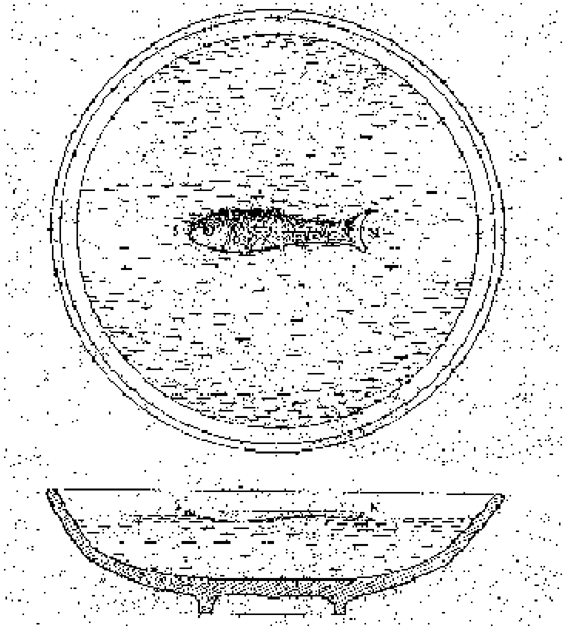
100 A.D. China Invention of Compass

Known in Europe only by 12th century A.D.

Immediately found use in Europe as navigational device, unlike China, where it remained largely a curiosity.



magnetized spoon on plate

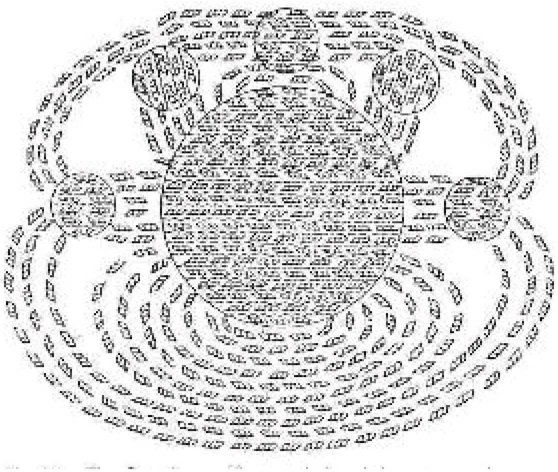


floating magnetic fish 1040 A.D.

History of magnetism (cont'd)

<u>1269 A.D.</u> Poles of magnet discovered.

Petrus Peregrinus - wrote first treatise on exp'tl magnetism. Put iron filings in various places around spherical lodestone, mapped out orientations and noticed streamlines converged at N and S poles.



<u>1600</u> Publication of *de Magnete* by William Gilbert

• Repeated Peregrinus' experiments, great exponent of experimental method.

• Disproved superstitions saying garlic, onion, and diamonds could rob magnets of their power.

• Recognized that earth itself was a magnet, and that magnetic poles did not quite coincide with real poles.

History of magnetism (cont'd)

"A man offered to sell me a secret for permitting one to speak, through the attraction of a certain magnet needle, to someone distant two or three thousand miles, and I said to him that I would be willing to purchase it, but that I would like to witness a trial of it, and that it would please me to test it, I being in one room and he in another. He told me that, at such short distance, the action could not be witnessed to advantage; so I sent him away, and said that I could not go just then to Egypt or Muscovy to see his experiment, but that if he would go there himself, I would stay and attend to the rest in Venice." Galileo, 1632

History of magnetism (cont'd)

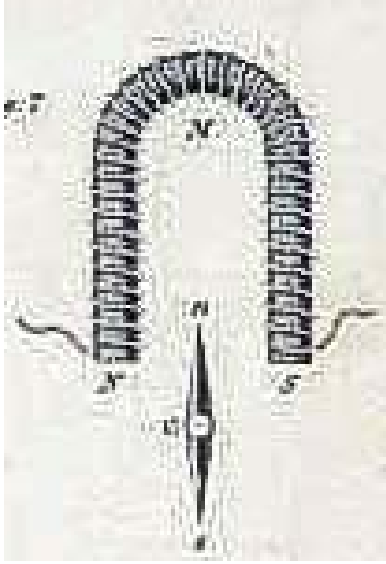
1600-1820 Questions about connection between electricity & magnetism

1681, ship struck by lightning has compass reversed. Failed attempts to create 2-fluid theory of magnetism like electricity. Most believe they are distinct phenomena.

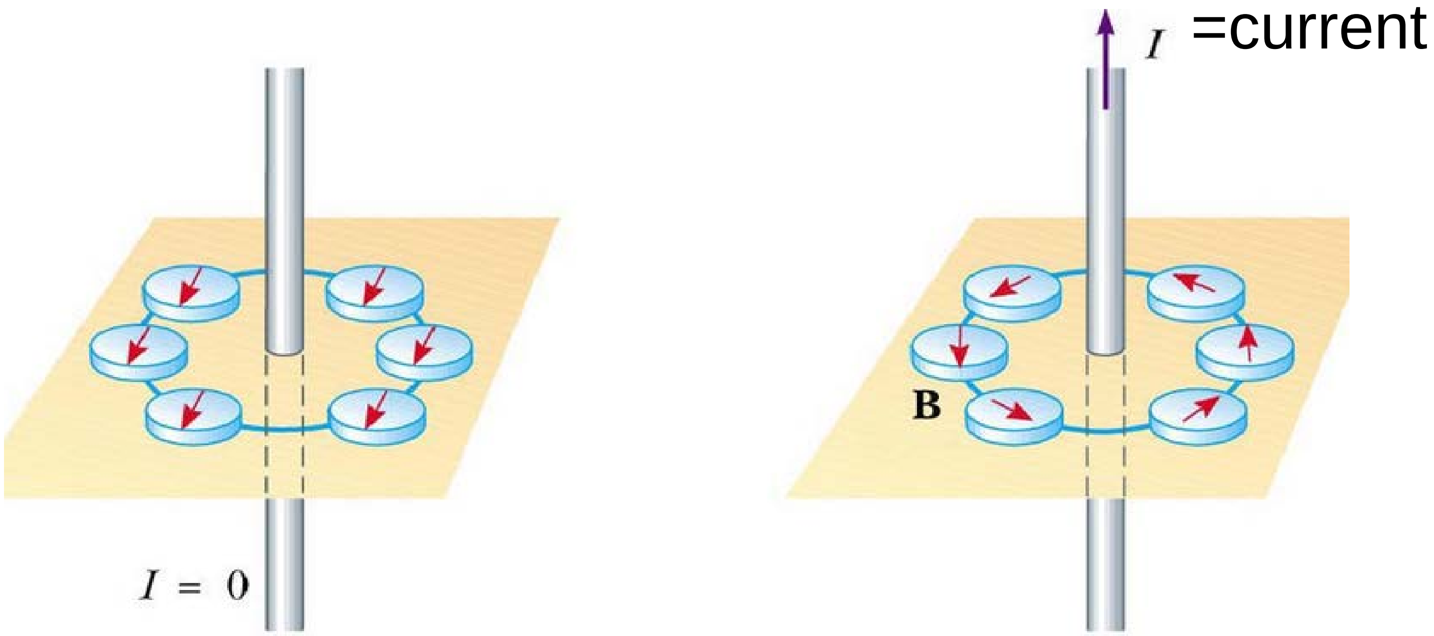
1820 Hans Christian Oersted experiment

Electric current in wire deflects compass needle nearby. July 1820, description of experiment published in latin.

Prof. at U. Copenhagen



Magnetism: a “circular” rather than central force



Oersted influenced by stay in Germany (Jena school of philosophy), in particular, Friedrich Schelling, who considered nature as a “world soul”, resulting from interplay of attractive & repulsive forces. From this standpoint, he expected and was looking for a connection between electricity and magnetism. Reported an effect, “confused” and “feeble”.

History of magnetism (cont'd)

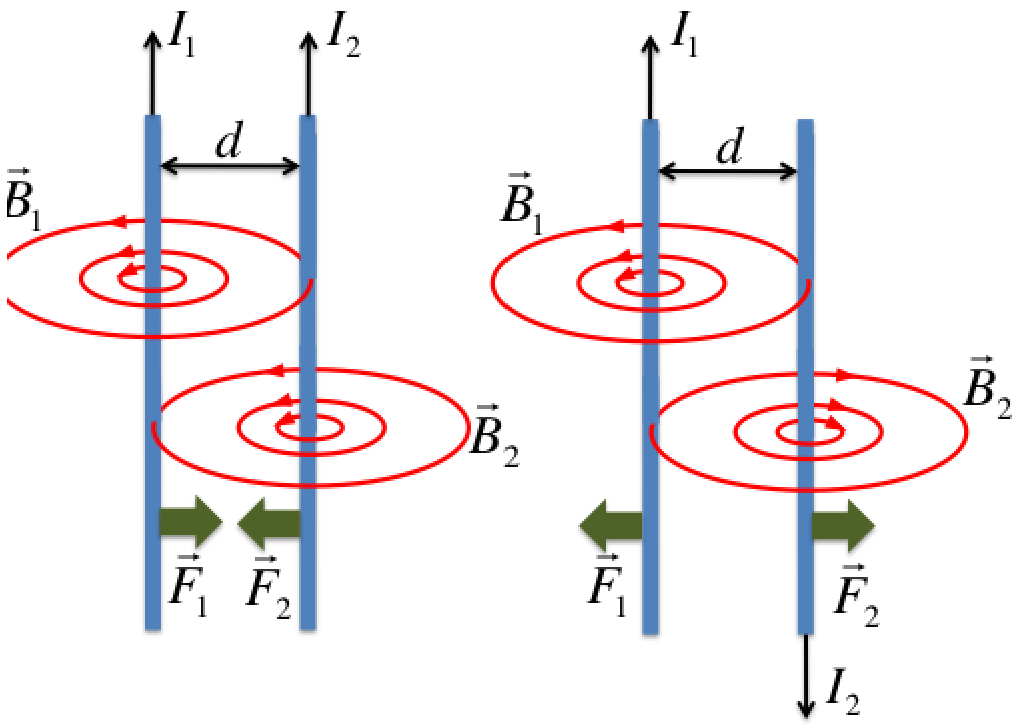
September 11,1820 Dominique Arago reports Oersted discovery to French Academy of Sciences. Announces own discovery that current in wire acts like ordinary magnet, attracting filings & inducing permanent magnetism in iron needles.

September 18, 1820 André Marie Ampère puts forward theory of magnetism due to internal circulating currentsReports experiments indicating force between current-carrying wires is attractive if two wires carry current in same direction, repulsive otherwise.

November 6, 1820 Ampère-Arago experiment reporting strong magnetization of needle in coil of wire.

November 16,1820 Similar results reported by Sir Humphrey Davy

Demo: Ampère: force between two current-carrying wires.



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Magnetism

Just as we have gravitational forces between two masses and electric forces between two electrically charged objects, there are magnetic forces between two magnetized objects

The “charges“ in magnetization are called poles

- Magnetized objects have a north pole and a south pole

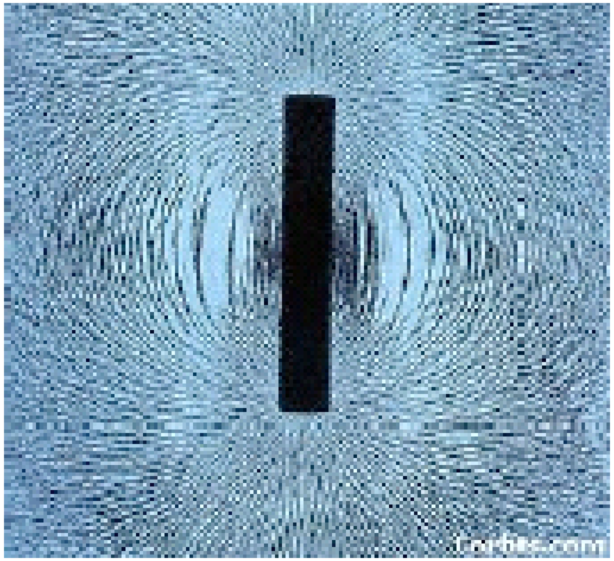
Just like the electric force, the magnetic force can be either attractive or repulsive

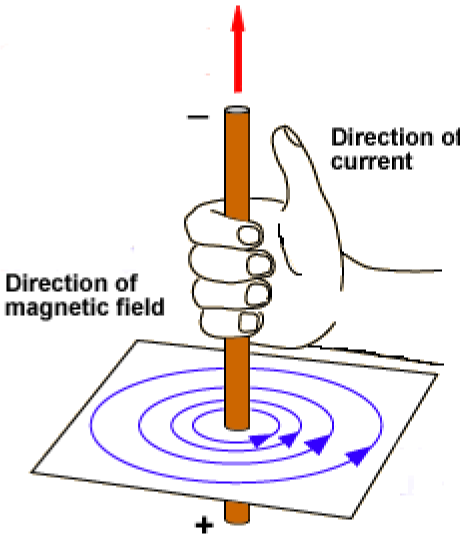
- Poles with the same magnetization repel
- Poles with the opposite magnetization attract

Unlike electric charges, magnetic poles cannot be separated!

Magnetic fields

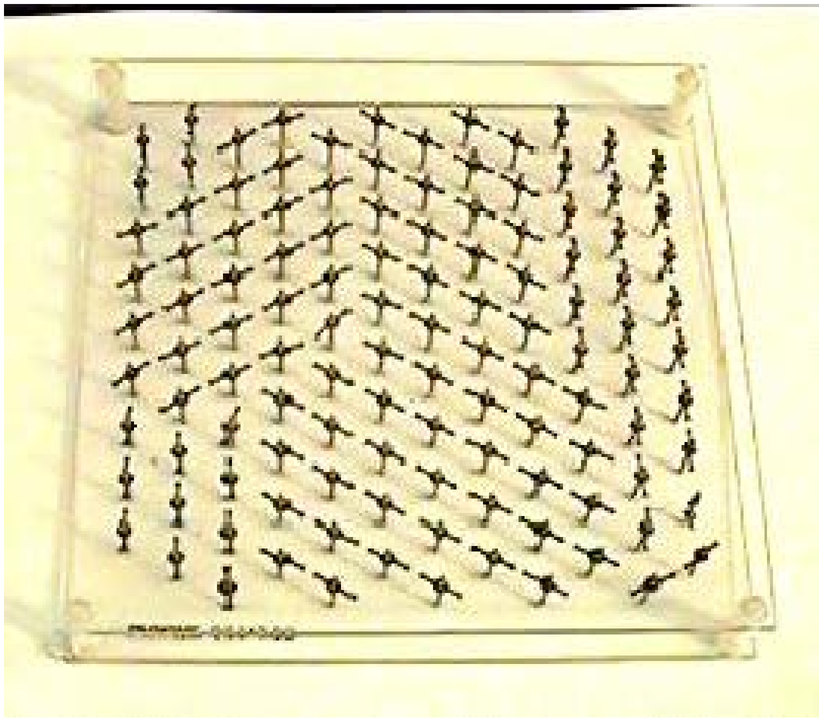
Michael Faraday (1781-1867) imagined lines of a "force field" that extended into space around a magnet.
The "magnetic field" at a point in space provides a force if a magnet or current is placed there





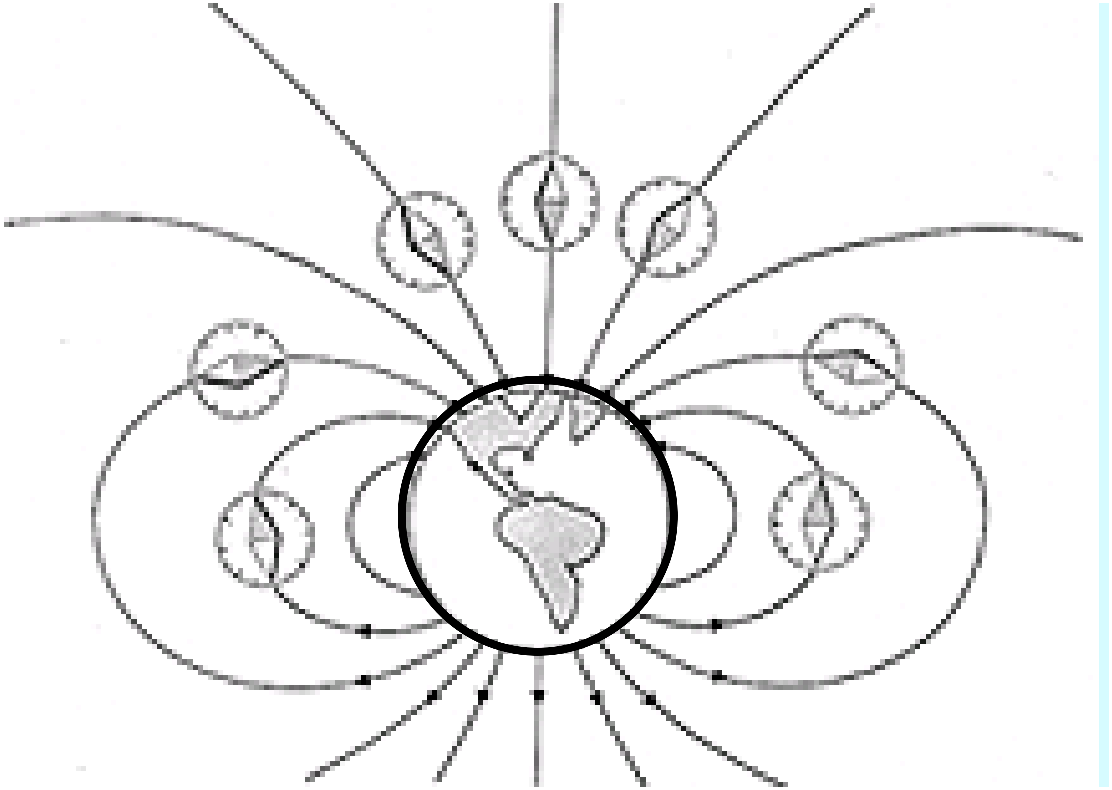
Permanent magnets (e.g. iron)

In some materials each atom has a tiny *magnetic moment* which acts like a tiny bar magnet. These *moments* like to line up with each other, like bar magnets, but sometimes disorder in the material prevents this, and they only line up in a small portion of the sample, called a *magnetic domain.* You can't tell that the material is magnetic inside until you apply a large external field to it, *aligning the domains.* Then you have a good permanent magnet.



The earth is a permanent magnet

Circulating electric currents in central core cause:



…which is why compasses work