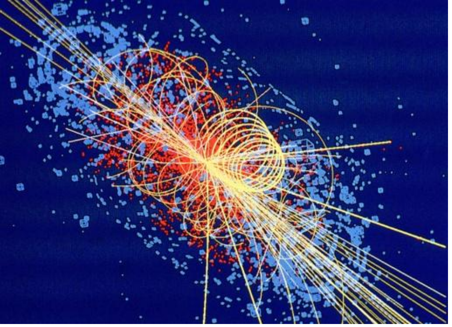
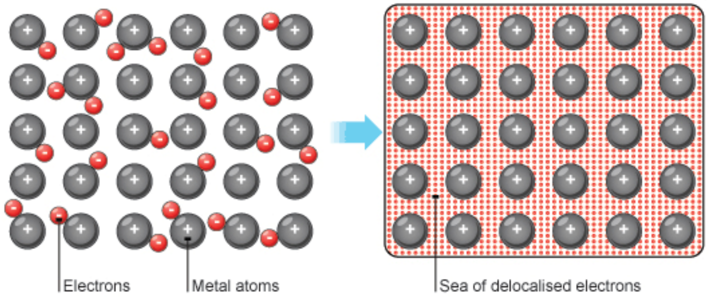
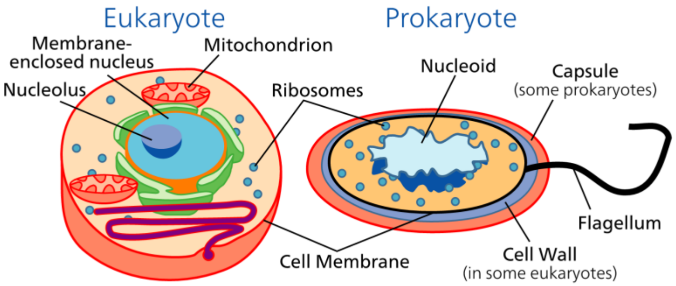
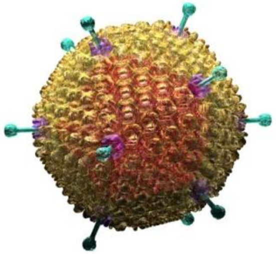
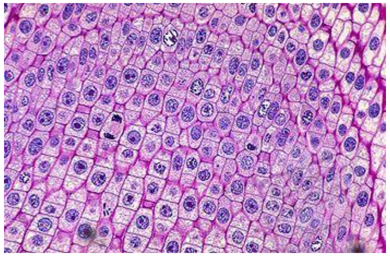


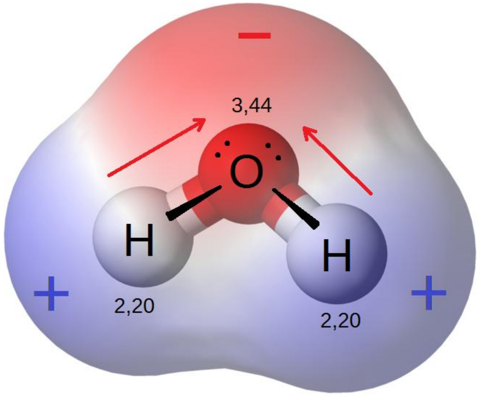


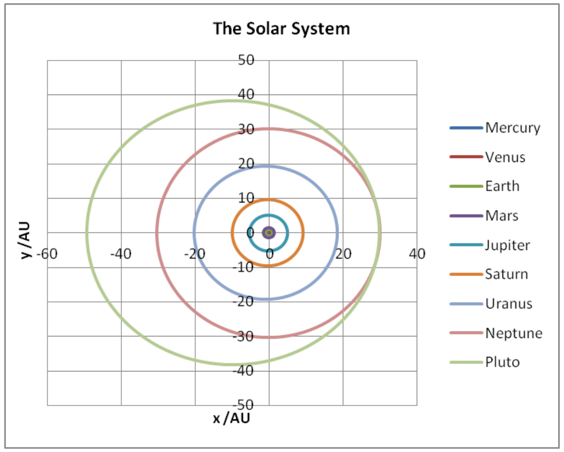




Matter & Forces



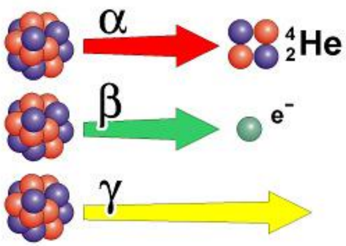


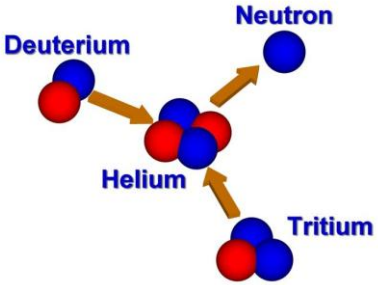


Universe by Numbers: Day 2

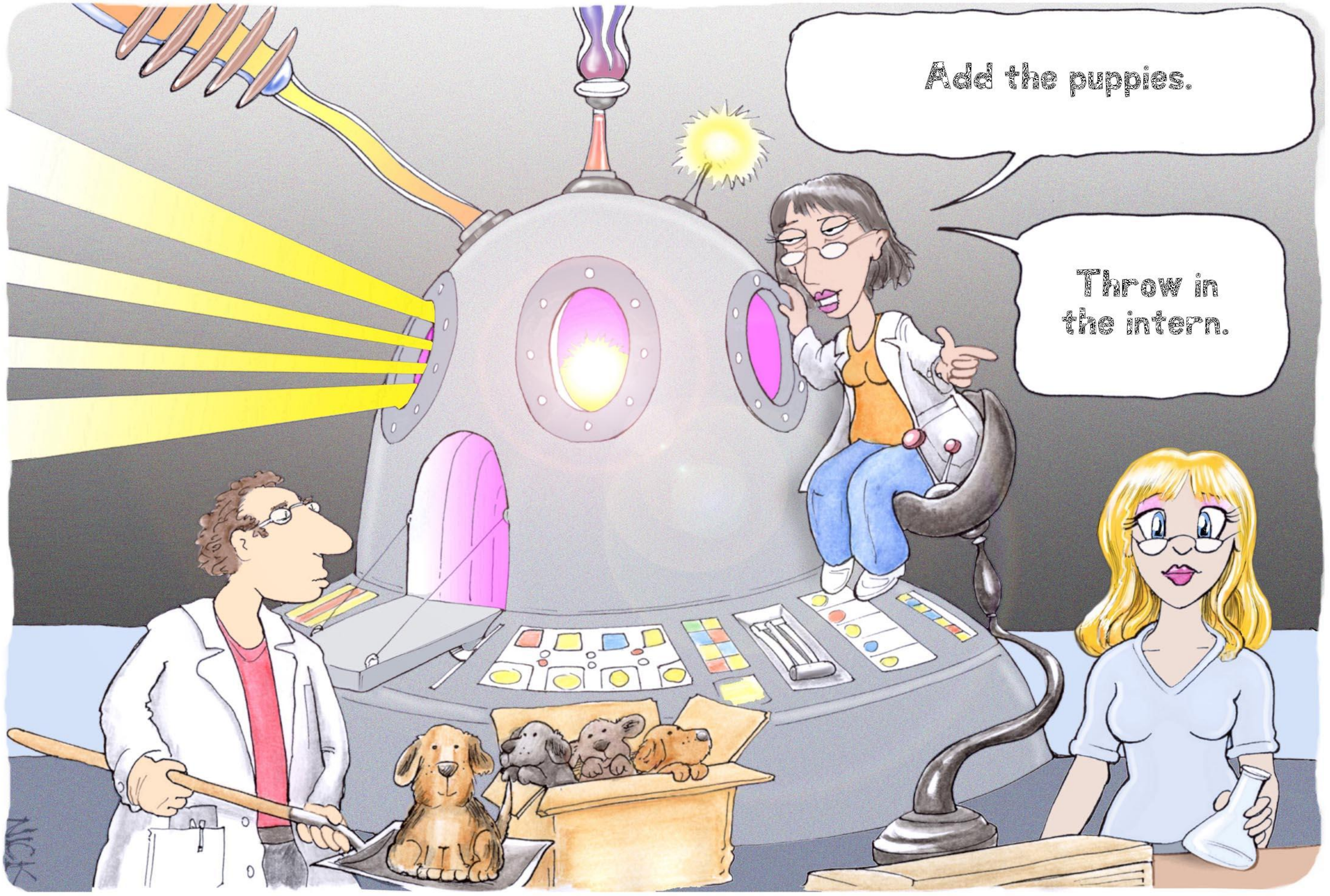
July 2016

Dr Andrew French



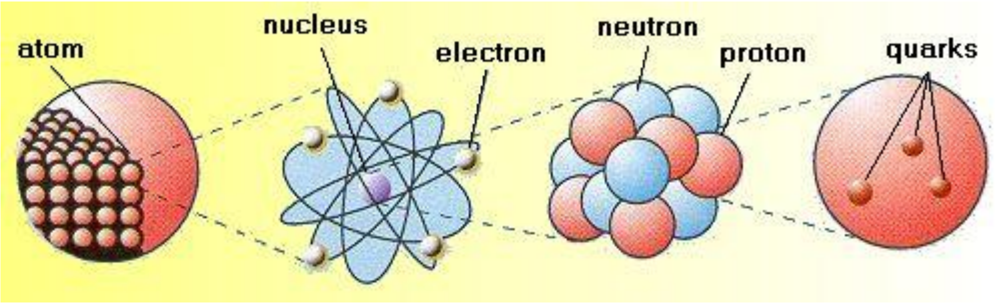


http://www.freethunk.net/nickkim/nickkim.php



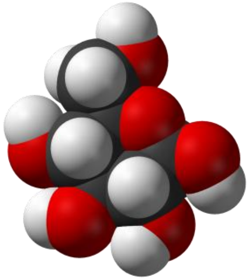
After years of experimentation, scientists remain dubious about whether there really IS such a thing as the Cute Particle.

Length scales

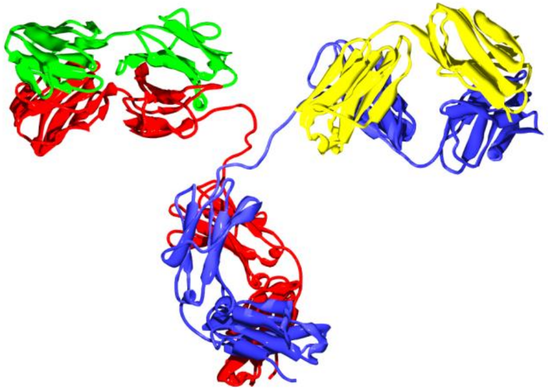


10^{-10} m 10^{-15} m

Glucose molecule

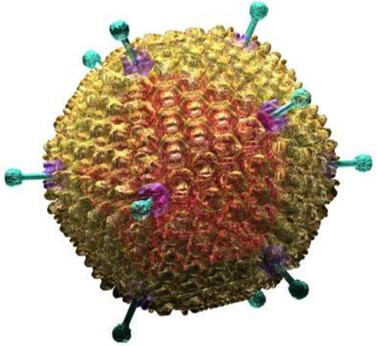


10^{-9} m



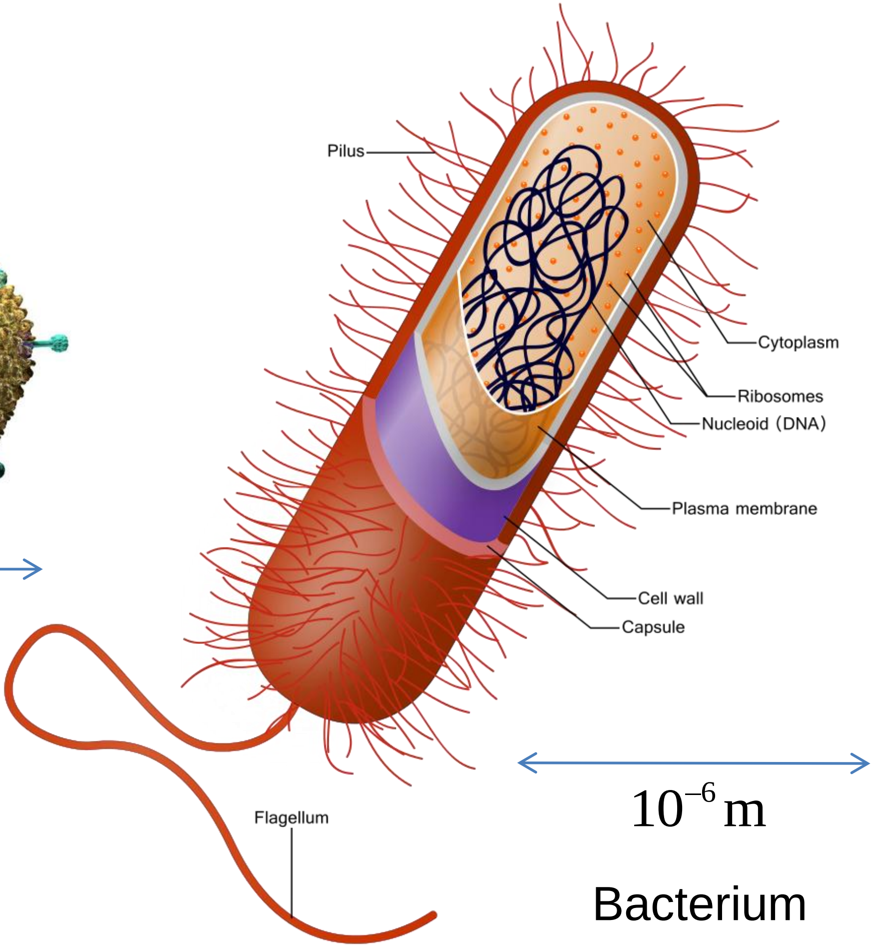
10^{-8} m

Antibody



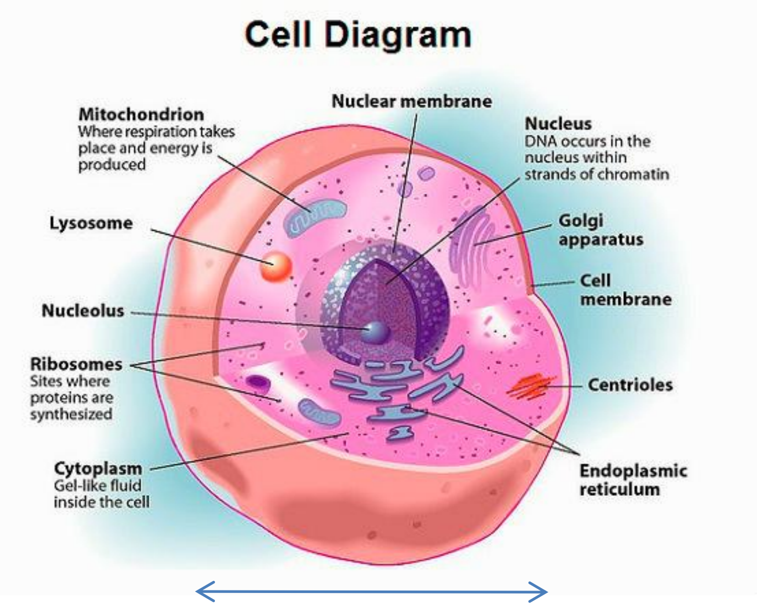
10^{-7} m

Virus



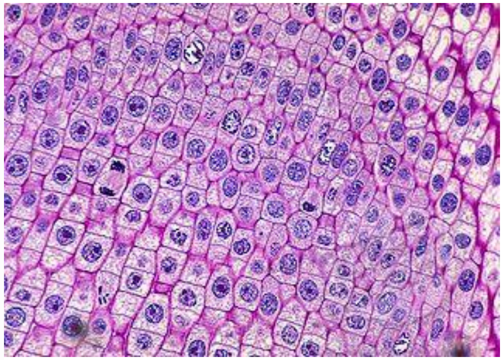
10^{-6} m

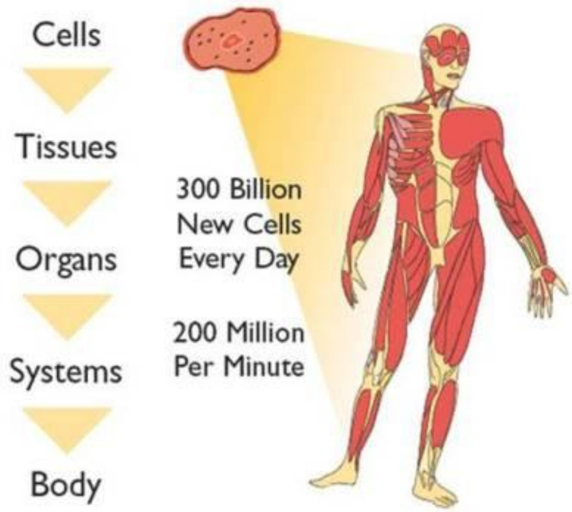
Bacterium

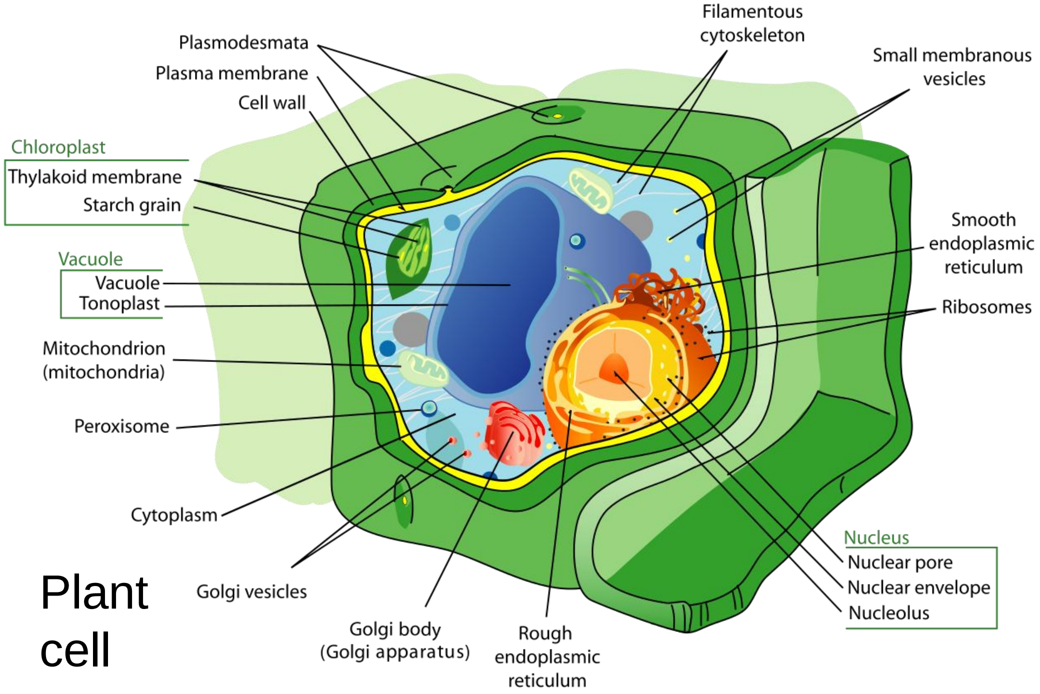


10^{-5} m

Human cell



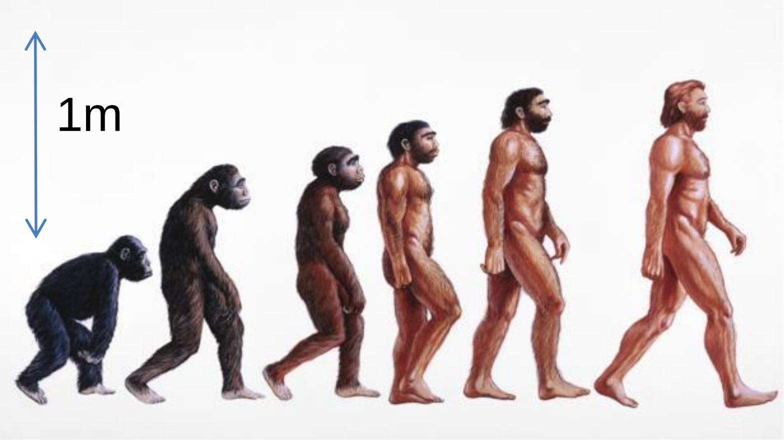




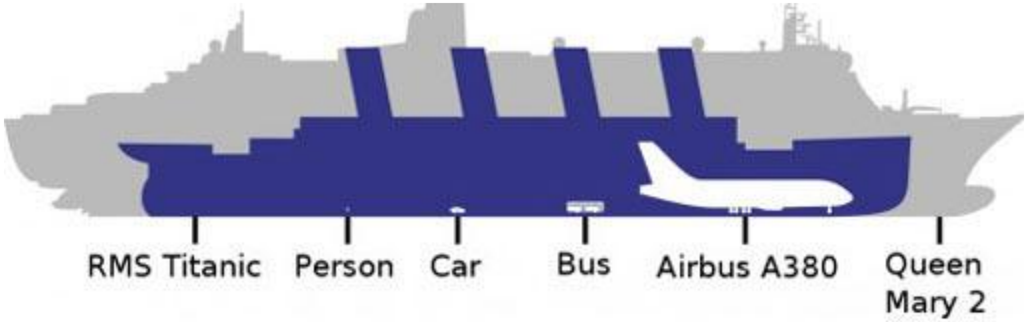
Plant cell

10^{-2} m

Human eye

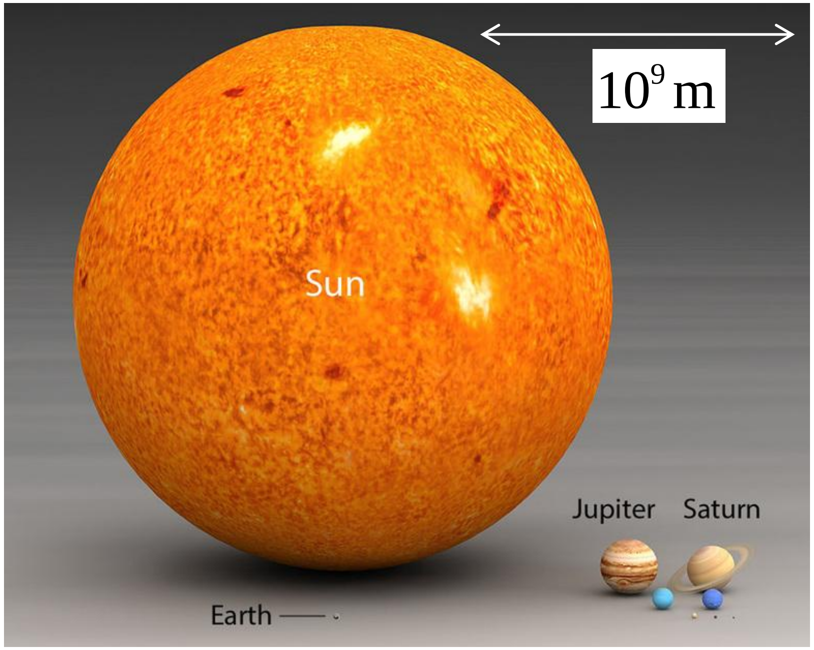


1m



10^2 m

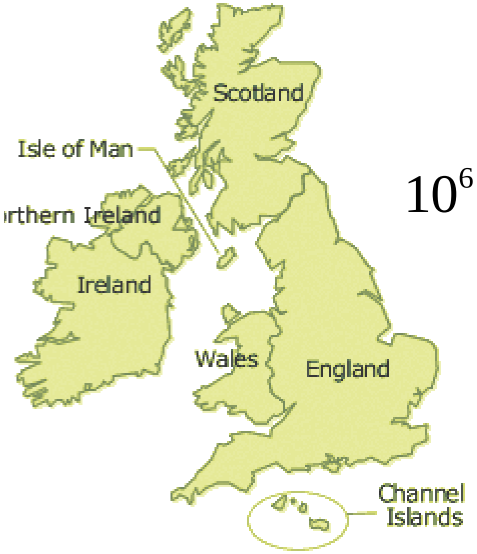
10^4 m



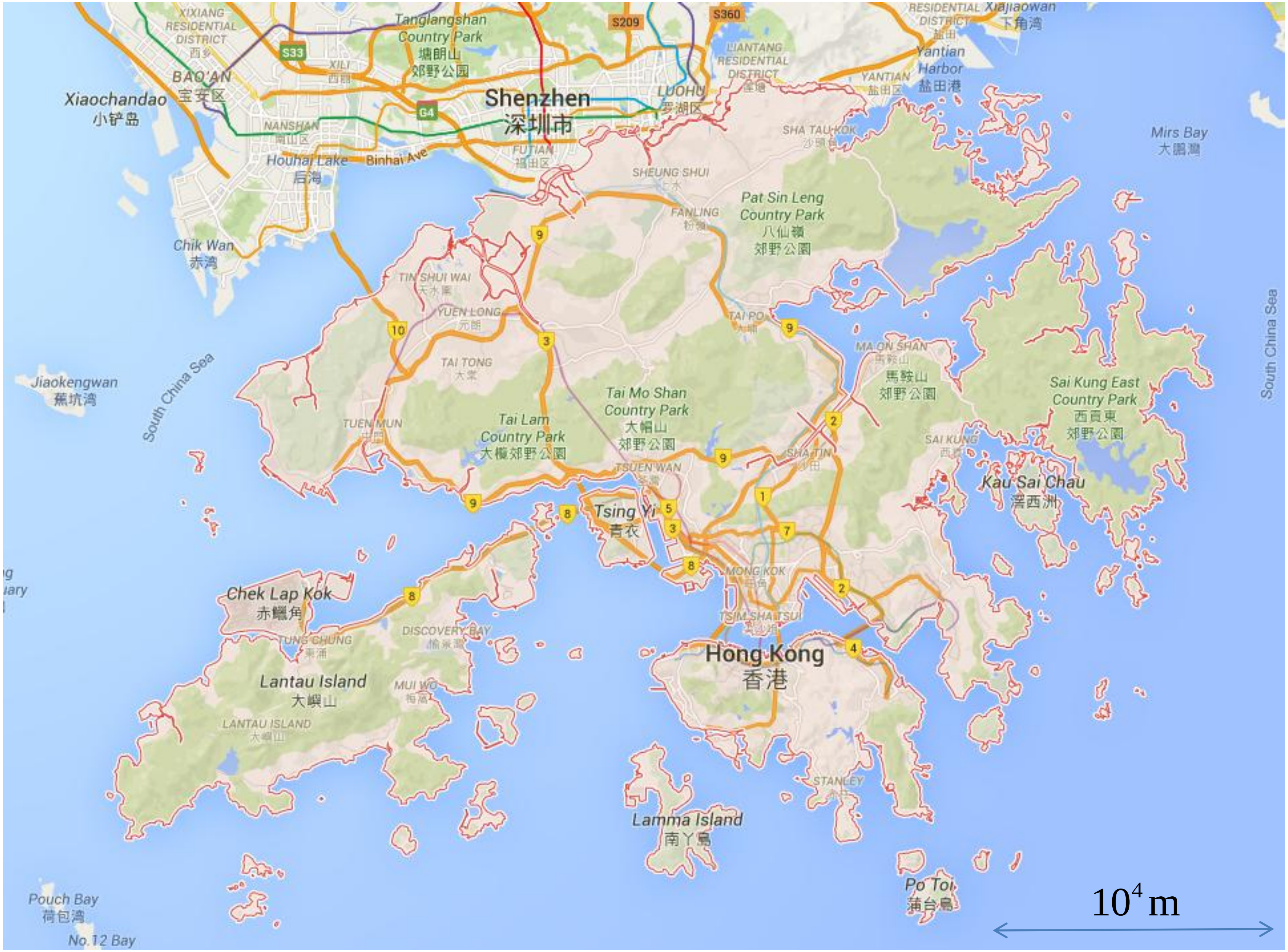
10^9 m

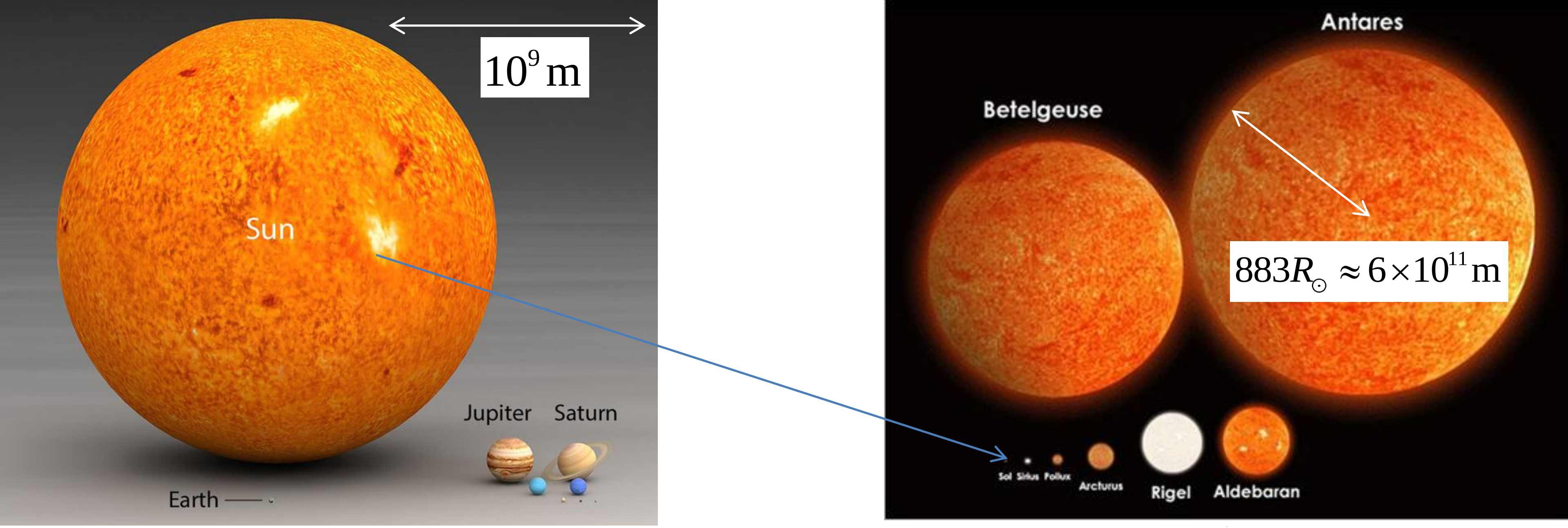
10^7 m

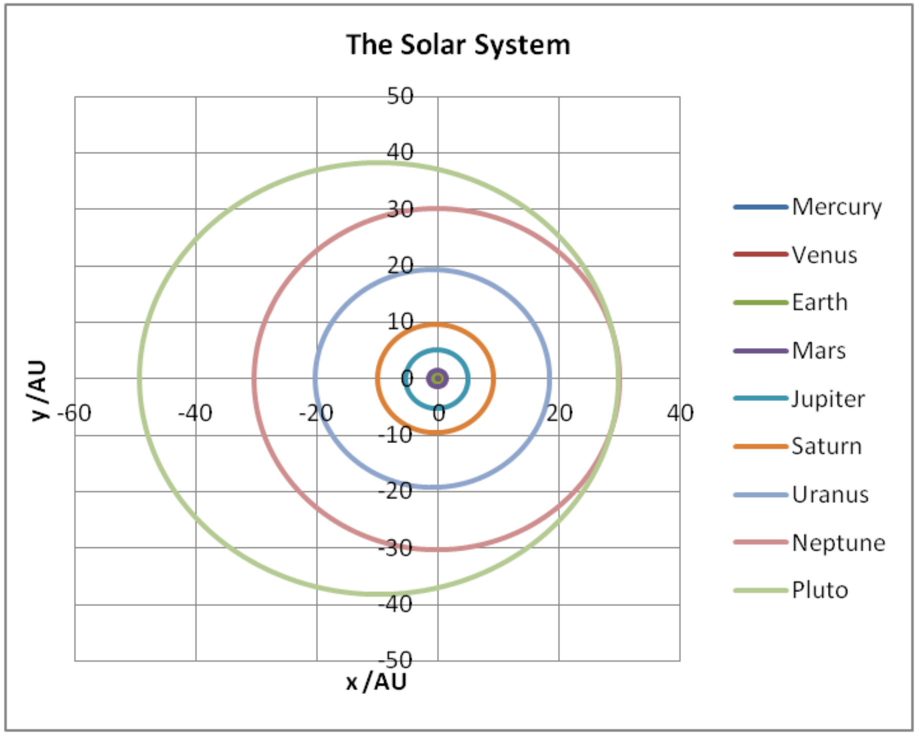
Earth diameter
= 12,756km



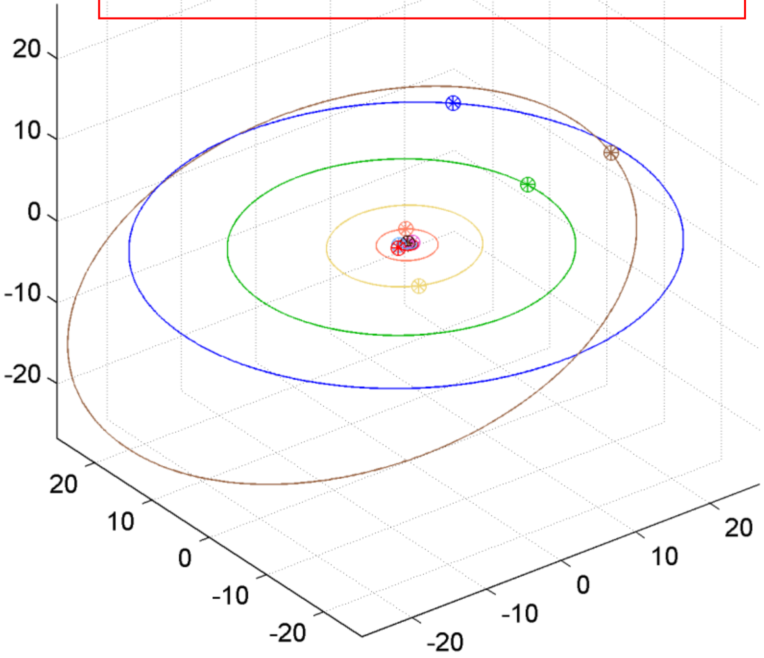
10^6 m

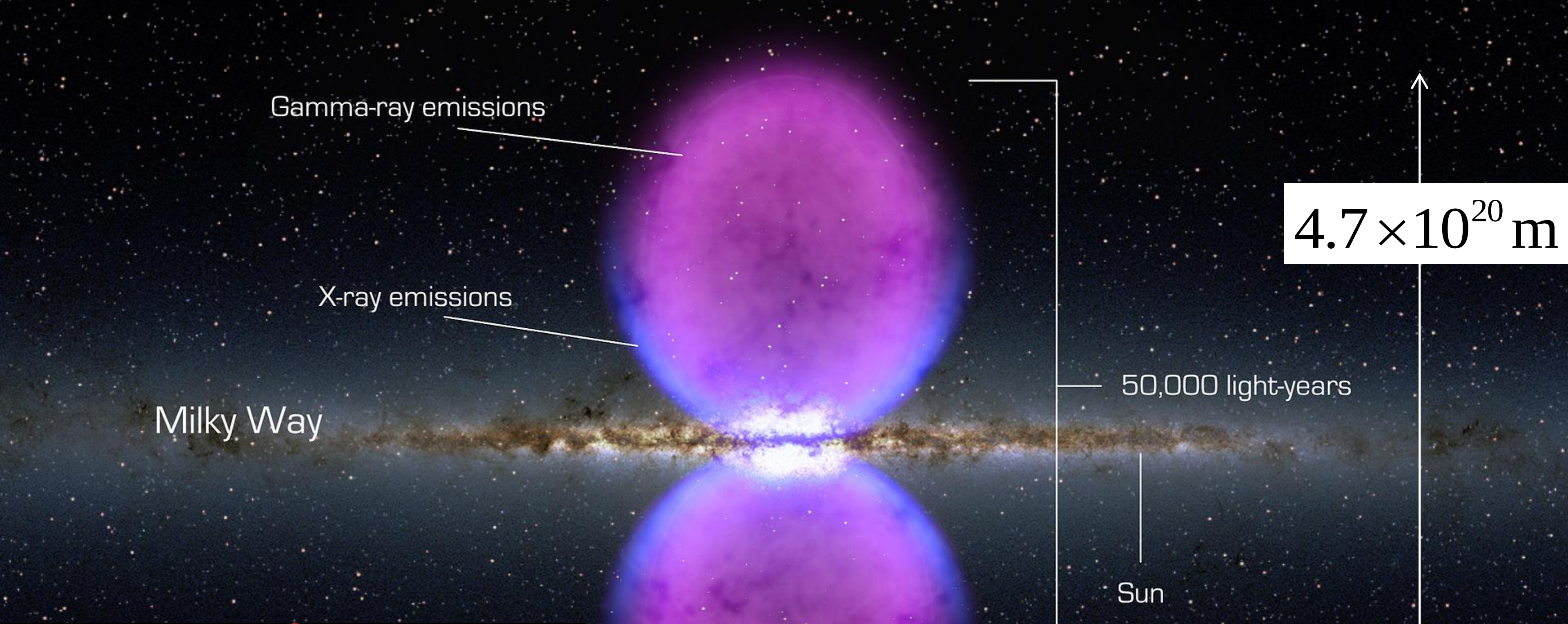

Shenzhen
深圳市
Tanglangshan Country Park
塘朗山郊野公园
XIXIANG RESIDENTIAL DISTRICT
西乡
BAO'AN
宝安区
XILI
西丽
Xiaochandao
小铲岛
NANSHAN
南山区
Houhai Lake
后海
Binhai Ave
FUTIAN
福田区
LUOHU
罗湖区
LIANTANG RESIDENTIAL DISTRICT
YANTIAN
盐田区
Yantian Harbor
盐田港
RESIDENTIAL DISTRICT
Xiajiaowan
下角湾
Mirs Bay
大鵬灣
S33
G4
S209
S360
Chik Wan
赤湾
SHA TAU KOK
沙頭角
SHEUNG SHUI
FANLING
粉嶺
Pat Sin Leng Country Park
八仙嶺郊野公園
TIN SHUI WAI
天水圍
YUEN LONG
元朗
TAI TONG
大棠
TAI PO
大埔
MA ON SHAN
馬鞍山
馬鞍山郊野公園
Sai Kung East Country Park
西貢東郊野公園
SAI KUNG
西貢
Kau Sai Chau
滘西洲
Jiaokengwan
蕉坑湾
South China Sea
TUEN MUN
屯門
Tai Lam Country Park
大欖郊野公園
Tai Mo Shan Country Park
大帽山郊野公園
TSUEN WAN
荃灣
SHA TIN
沙田
Tsing Yi
青衣
MONG KOK
旺角
TSIM SHA TSUI
尖沙咀
Chek Lap Kok
赤鱲角
TUNG CHUNG
東涌
DISCOVERY BAY
愉景灣
Lantau Island
大嶼山
LANTAU ISLAND
大嶼山
MUI WO
梅窩
Hong Kong
香港
STANLEY
赤柱
Lamma Island
南丫島
Po Toi
蒲台島
Pouch Bay
荷包湾
No.12 Bay
10
9
3
2
1
5
8
7
4
10^4 m



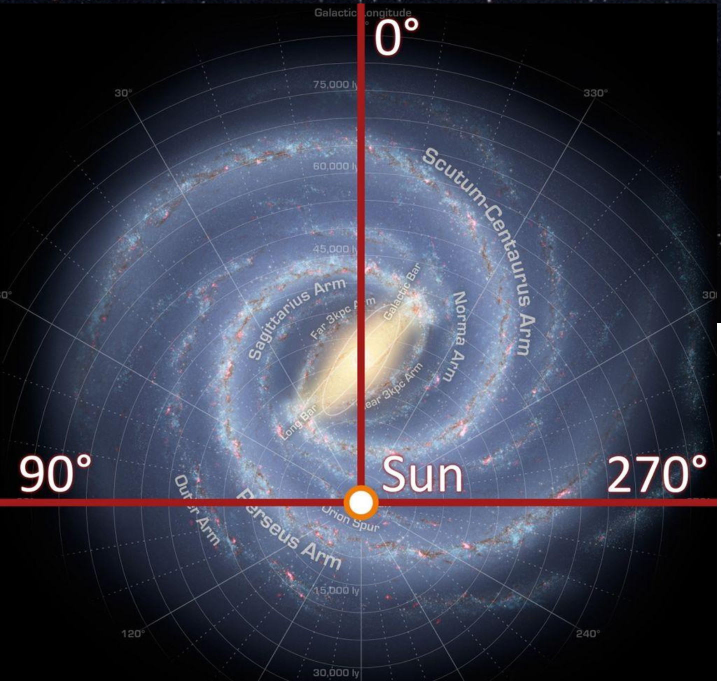


$$1\text{AU} = 1.496\times10^{11}\,\text{m}$$





4.7×10^{20} m

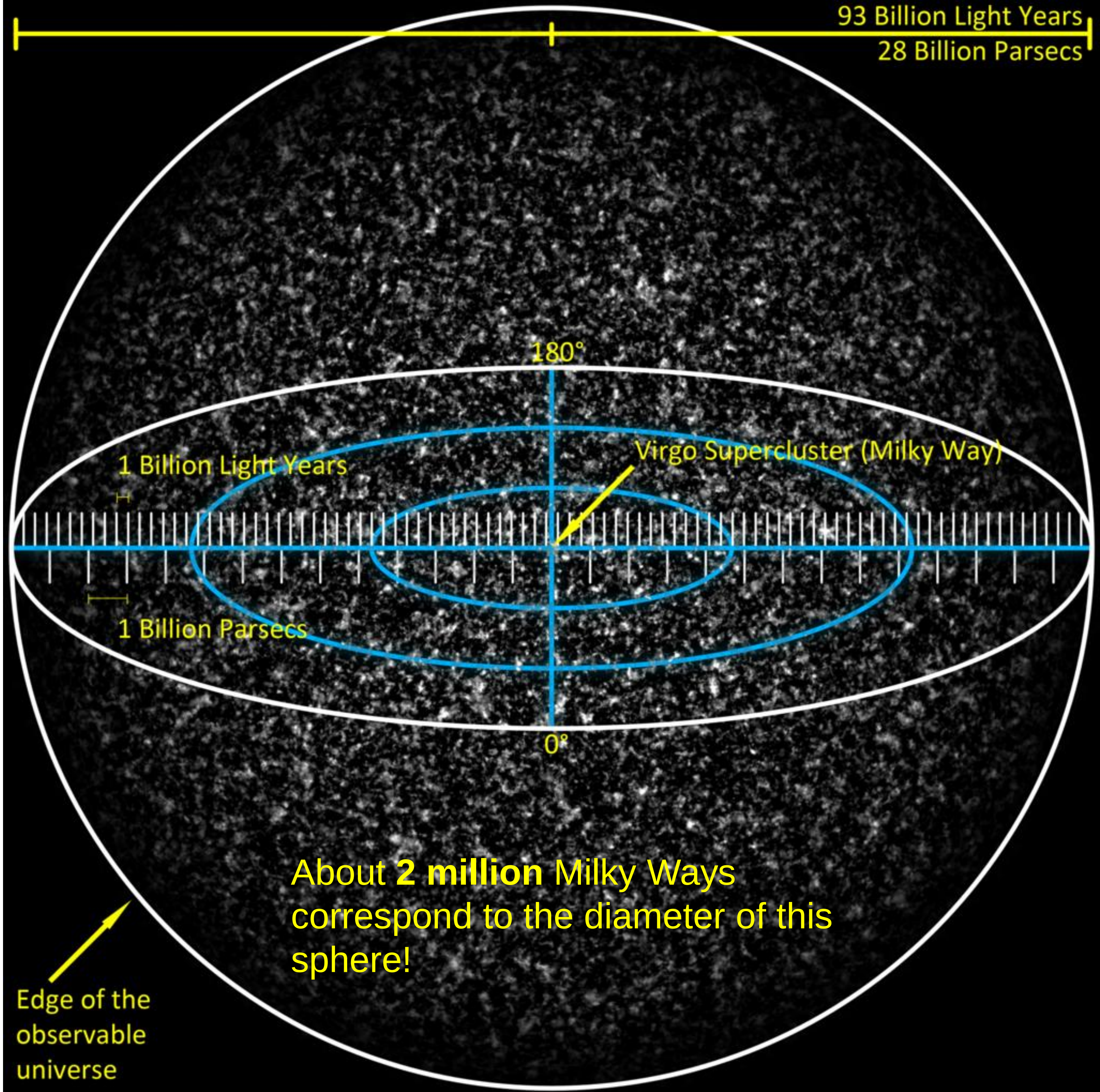


1 light year

9.461×10^{15} m

↔

10^{26} m

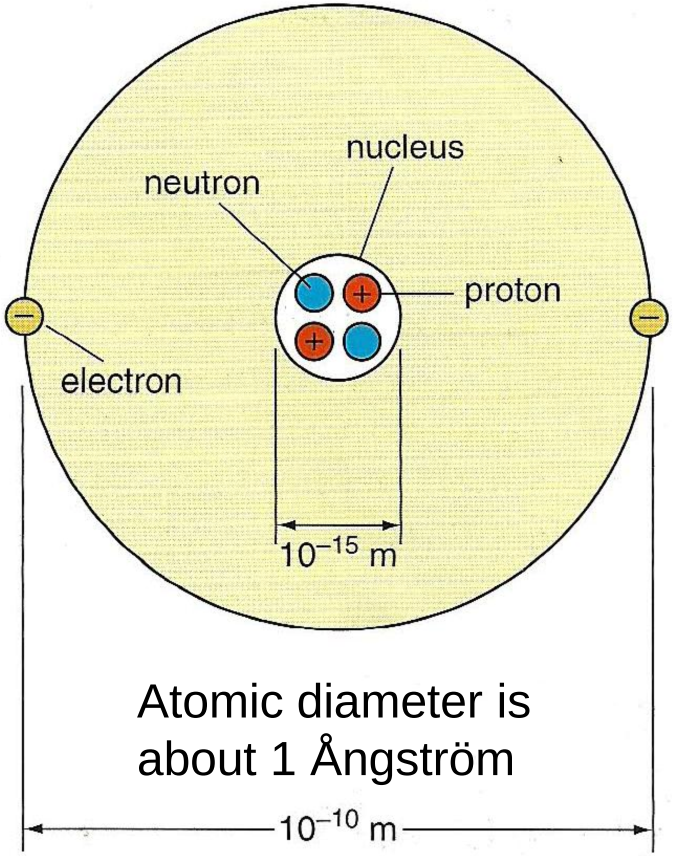


About **2 million** Milky Ways correspond to the diameter of this sphere!

1 light year

9.461×10^{15} m

The size of an atom



Earth diameter = 12,756km

Marble diameter = 3.6cm

Atomic diameter is about 1 Ångström

$$\left(\frac{1.2756\times10^{7}}{3.6\times10^{-2}}\right)^{3}\approx\boxed{4.4\times10^{25}}$$

Volume of Earth in marbles

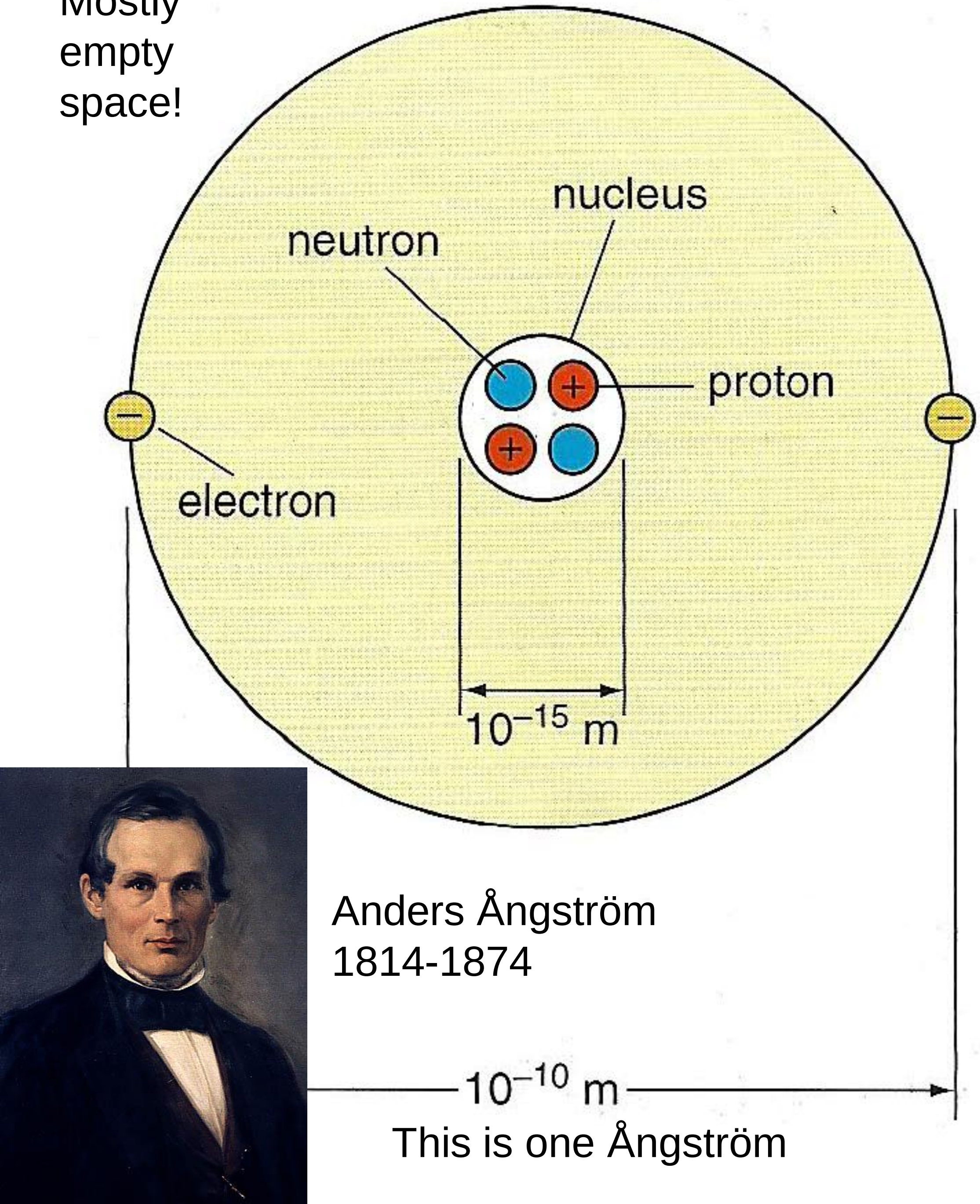
$$\left(\frac{3.6\times10^{-2}}{1\times10^{-10}}\right)^{3}\approx\boxed{4.7\times10^{25}}$$

Number of atoms in a marble

There are as many atoms in a marble as an Earth made of marbles!

Atomic mass and density

Mostly
empty
space!



Anders Ångström
1814-1874

This is one Ångström

$$m_e = 9.109 \times 10^{-31}\,\text{kg}$$

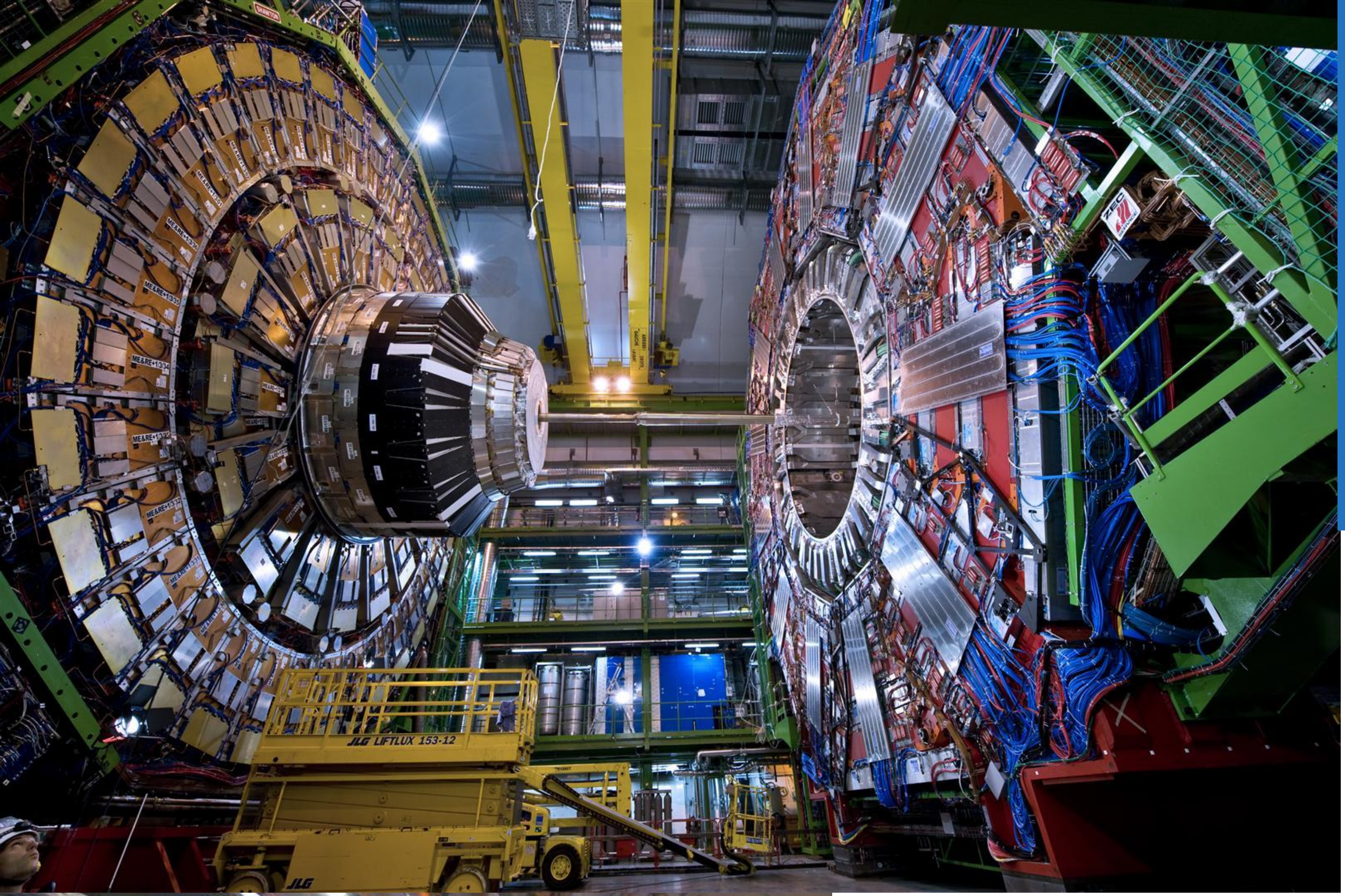
$$m_p = 1.673 \times 10^{-27}\,\text{kg}$$

$$m_n = 1.675 \times 10^{-27}\,\text{kg}$$

$$\rho \approx \frac{1.673 \times 10^{-27}\,\text{kg}}{\frac{4}{3}\pi \times \left(\frac{1}{2} \times 10^{-10}\right)^3}$$

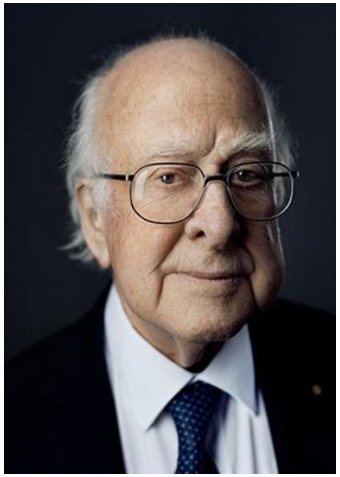
$$\rho \approx \boxed{3{,}200\,\text{kgm}^{-3}}$$

$$\rho_{water} \approx 1{,}000\,\text{kgm}^{-3}$$

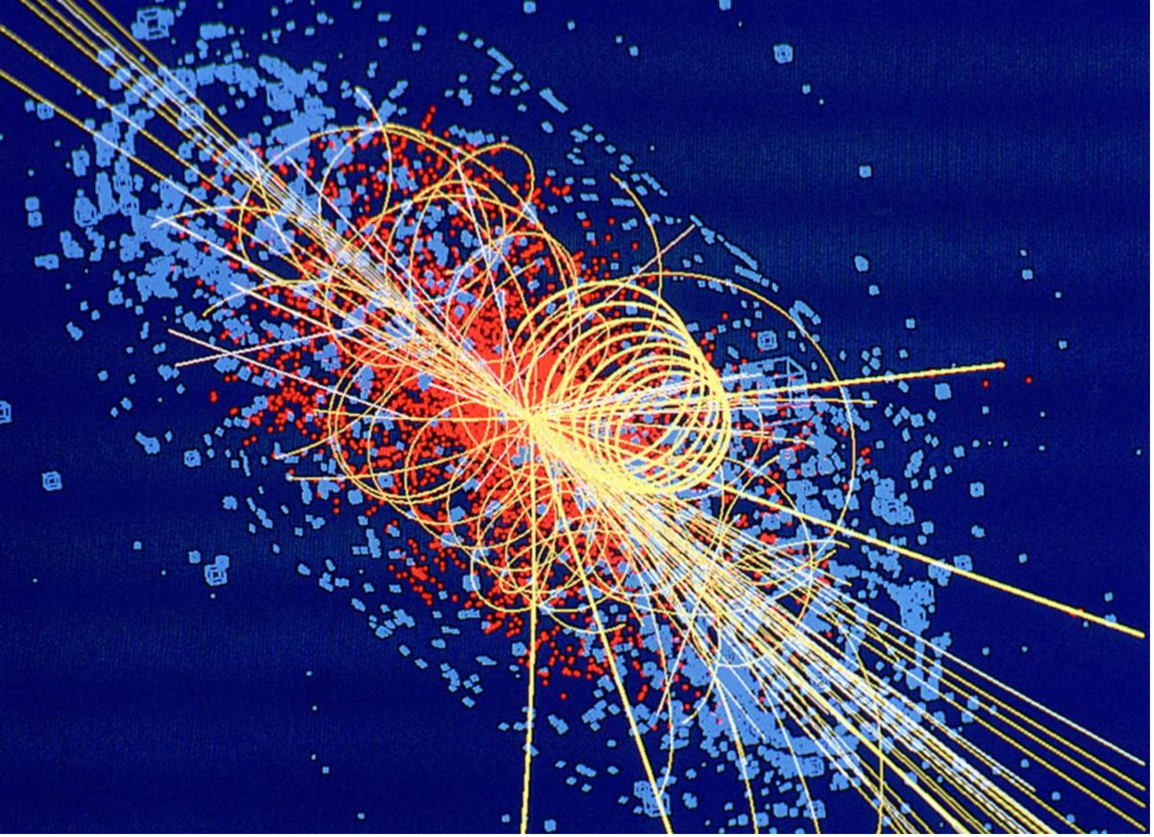


Higgs boson discovered
at CERN in July 2012

All particles are within
the **Higgs field**.
Interactions with it confer
mass to certain particles.



Peter Higgs
1929-



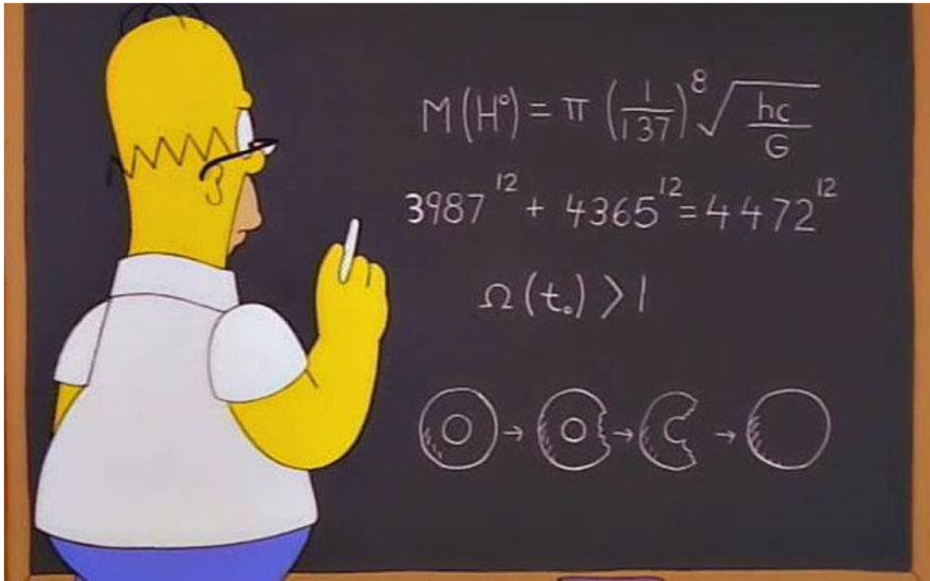
At CERN, particles (such as protons) are collided at very high energies. The high energies are achieved via acceleration using **electric fields**. Enormous* voltages are used!

Magnetic fields are used to steer the particle beams in the circular beamlines

* 10^{12} volts

When particles such as protons collide, a plethora of other particles (i.e. hadrons or leptons) are formed.

The trajectories of these particles can be used to infer the mass and charge of these particles



The Standard Model of Particle Physics

Fermions are particles with half-integer spin
They obey the **Pauli Exclusion Principle**

Matter

Leptons
Spin half

Lepton	Charge	Mass (MeV/c²)	Mean life (s)
ν_e	0	$< 15\,\mathrm{eV}/c^2$	stable
ν_μ	0	< 0.17	stable
ν_τ	0	< 18.2	stable
e	±1	0.511^a	stable
μ	±1	105.658^b	2.197×10^{-6c}
τ	±1	$1777.0(\pm 3)$	$290.0(\pm 12) \times 10^{-15}$

Hadrons (made from quarks)

Quarks (spin 1/2)			
Name	Flavour	Mass (GeV/c²)	Charge (e)
up	u	≈ 0.35	+2/3
down	d	$m_d \approx m_u$	−1/3
charm	c	1.5	+2/3
strange	s	0.5	−1/3
top	t	174(±5)	+2/3
bottom	b	4.5	−1/3

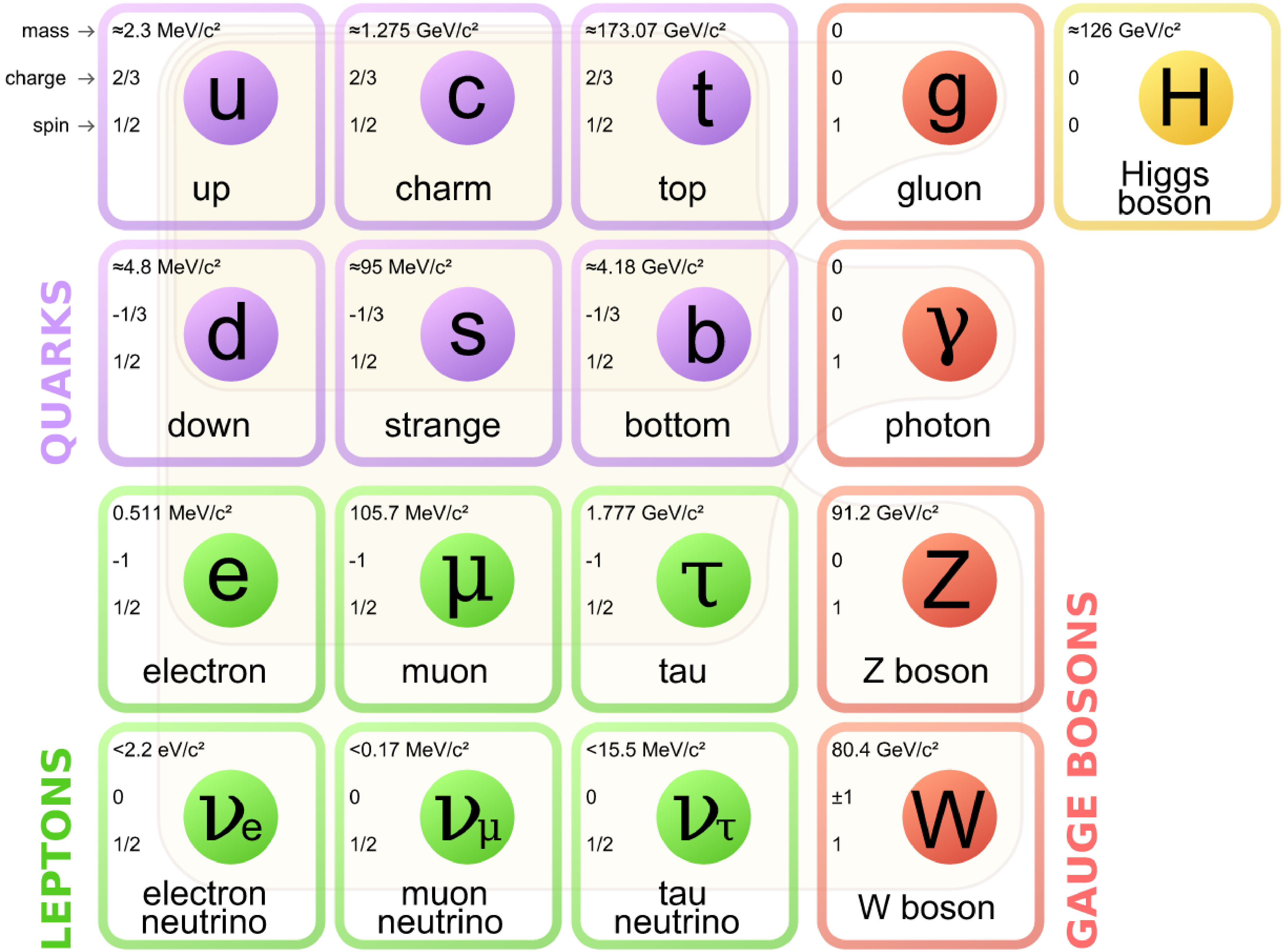
Baryons
(three quarks)
Half-integer spin

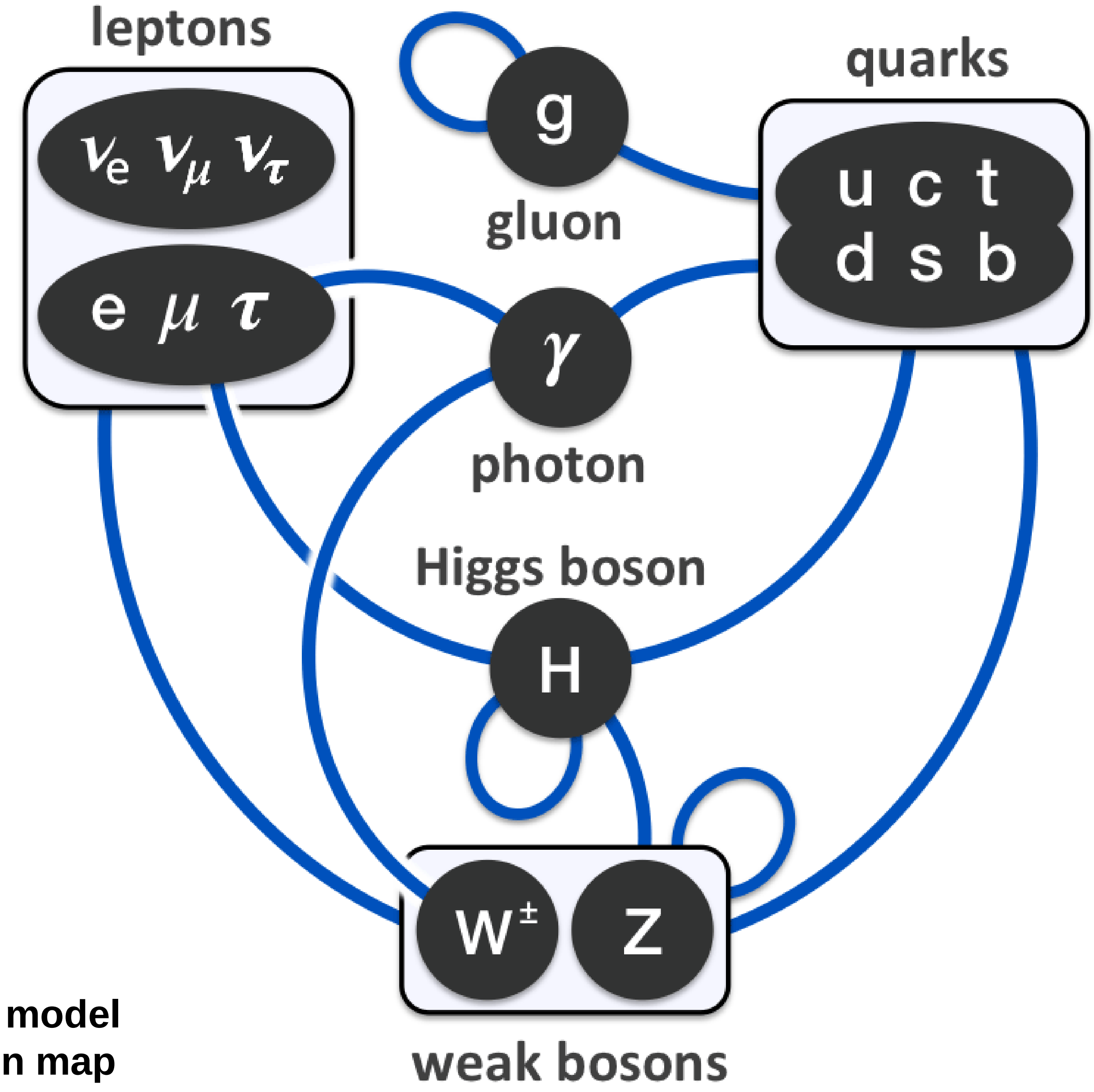
proton = uud
neutron = udd

Mesons (quark + anti-quark pair)
Integer spin

Mesons are also Bosons as they have integer spin. They *don't* have to obey the Pauli Exclusion Principle

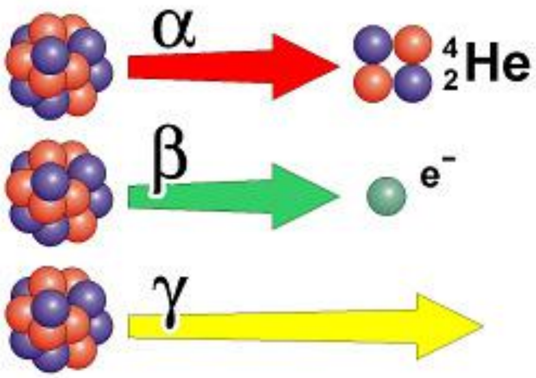
Interactions between particles proceed via exchange of **Gauge Bosons**
e.g. photon, W$^+$, W$^-$, Z^o, gluon, graviton(?)


mass →
charge →
spin →
≈2.3 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈173.07 GeV/c²
2/3
1/2
t
top
0
0
1
g
gluon
≈126 GeV/c²
0
0
H
Higgs boson
QUARKS
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
0.511 MeV/c²
-1
1/2
e
electron
105.7 MeV/c²
-1
1/2
μ
muon
1.777 GeV/c²
-1
1/2
τ
tau
91.2 GeV/c²
0
1
Z
Z boson
LEPTONS
<2.2 eV/c²
0
1/2
νe
electron neutrino
<0.17 MeV/c²
0
1/2
νμ
muon neutrino
<15.5 MeV/c²
0
1/2
ντ
tau neutrino
80.4 GeV/c²
±1
1
W
W boson
GAUGE BOSONS

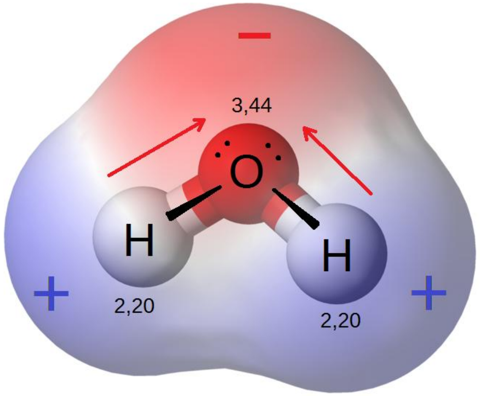


Standard model interaction map

Forces

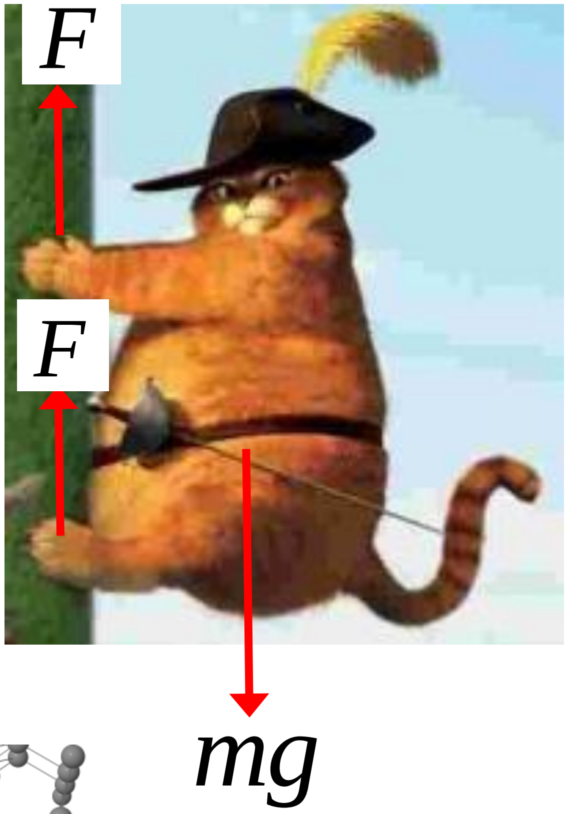


The **strong** and **weak** forces bind the particles together within the atomic nucleus

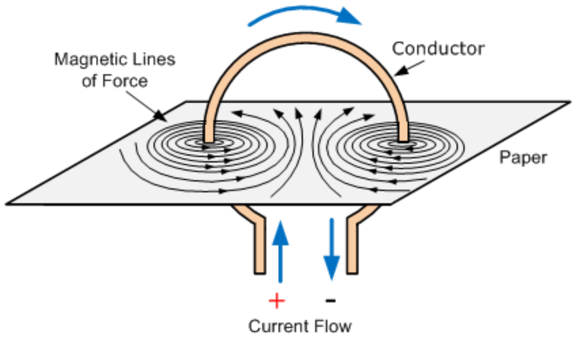


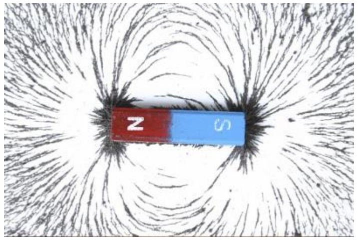
Electrical forces bind atoms together to form molecules.

A weighty puss indeed....

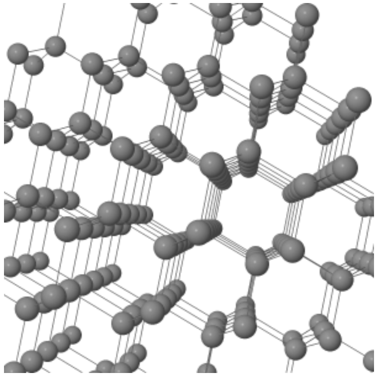


Gravity acts on all mass



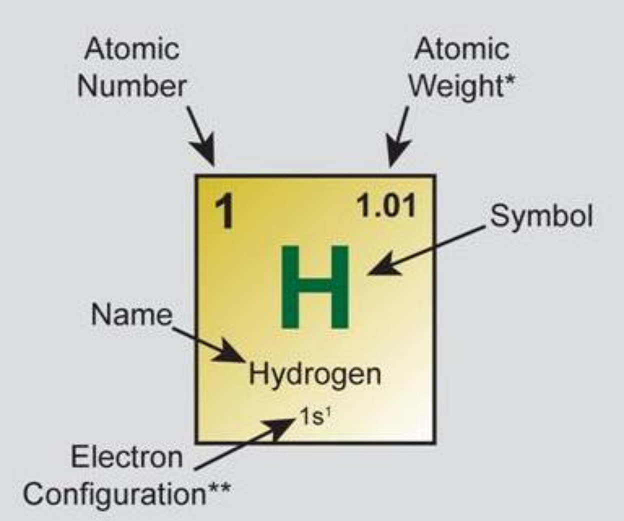


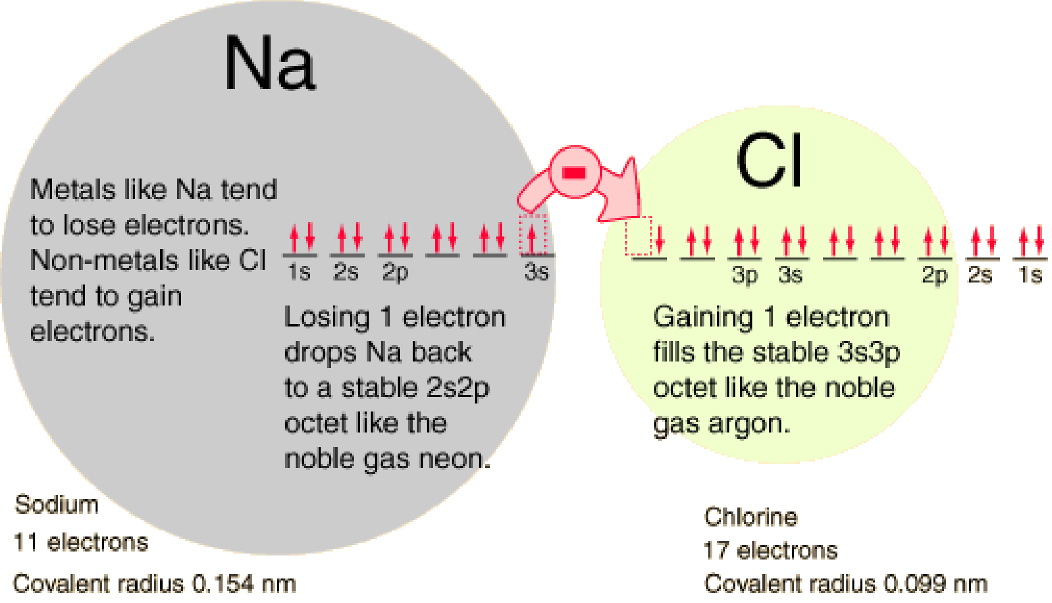
Magnetism is the electrical force resulting from *moving* charge



Groups of atoms result in the **macroscopic forces** we experience (i.e. **friction**)

Explaining Chemistry





Metals like Na tend to lose electrons. Non-metals like Cl tend to gain electrons.

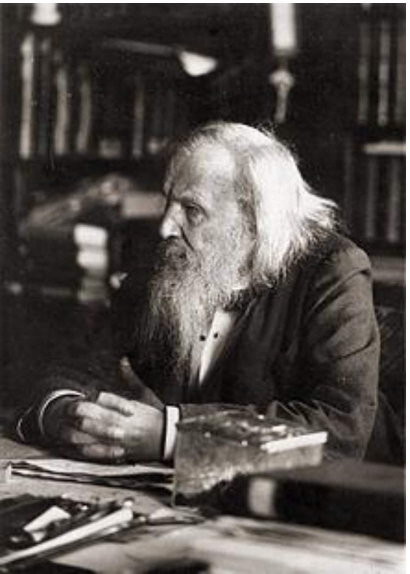
Losing 1 electron drops Na back to a stable 2s2p octet like the noble gas neon.

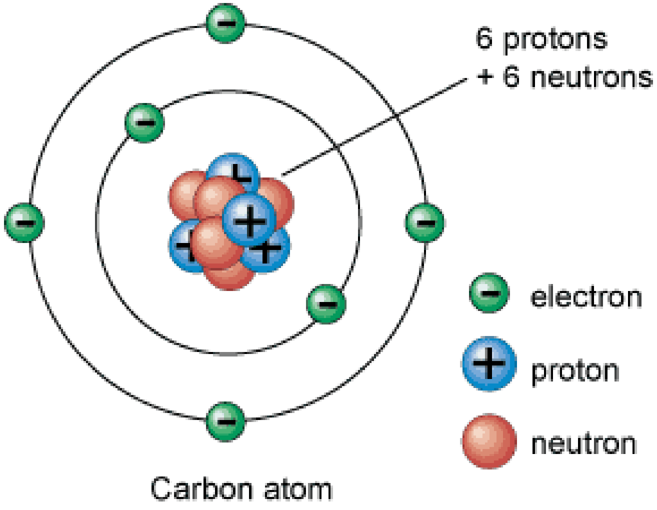
Gaining 1 electron fills the stable 3s3p octet like the noble gas argon.

Sodium
11 electrons
Covalent radius 0.154 nm

Chlorine
17 electrons
Covalent radius 0.099 nm

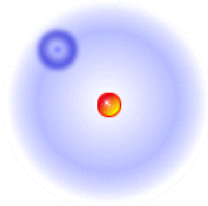
Dmitri Mendeleev
1834-1907

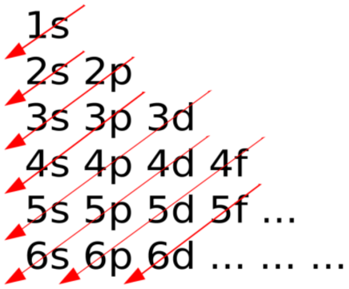




Carbon atom

Hydrogen Atom





Wolfgang Pauli
1900 – 1958

Periodic Table of the Elements

🟫 Alkali Metals
🟦 Alkaline Earth Metals
🟩 Transition Metals
🟨 Non-metals
🟥 Lanthanide Series
🟪 Actinide Series
🟦 Halogens
🟧 Inert Gases
⬛ Other Metals

Atomic Number
Atomic Weight*
1 1.01
H
Symbol
Name
Hydrogen
$1s^1$
Electron Configuration**

Period	Group 1 Ia	2 IIa	3 IIIb	4 IVb	5 Vb	6 VIb	7 VIIb	8 ←	9 VIIIb	10 →	11 Ib	12 IIb	13 IIIa	14 IVa	15 Va	16 VIa	17 VIIa	18 0
1	1 1.01 **H** Hydrogen $1s^1$																	2 4.00 **He** Helium $1s^2$
2	3 6.94 **Li** Lithium $1s^22s^1$	4 9.01 **Be** Beryllium $1s^22s^2$											5 10.81 **B** Boron $1s^22s^2p^1$	6 12.01 **C** Carbon $1s^22s^2p^2$	7 14.01 **N** Nitrogen $1s^22s^2p^3$	8 16.00 **O** Oxygen $1s^22s^2p^4$	9 19.00 **F** Fluorine $1s^22s^2p^5$	10 20.18 **Ne** Neon $1s^22s^2p^6$
3	11 22.99 **Na** Sodium $[Ne]3s^1$	12 24.31 **Mg** Magnesium $[Ne]3s^2$											13 26.98 **Al** Aluminum $[Ne]3s^2p^1$	14 28.09 **Si** Silicon $[Ne]3s^2p^2$	15 30.97 **P** Phosphorus $[Ne]3s^2p^3$	16 32.07 **S** Sulfur $[Ne]3s^2p^4$	17 35.45 **Cl** Chlorine $[Ne]3s^2p^5$	18 39.95 **Ar** Argon $[Ne]3s^2p^6$
4	19 39.10 **K** Potassium $[Ar]4s^1$	20 40.08 **Ca** Calcium $[Ar]4s^2$	21 44.96 **Sc** Scandium $[Ar]3d^14s^2$	22 47.87 **Ti** Titanium $[Ar]3d^24s^2$	23 50.94 **V** Vanadium $[Ar]3d^34s^2$	24 52.00 **Cr** Chromium $[Ar]3d^54s^1$	25 54.94 **Mn** Manganese $[Ar]3d^54s^2$	26 55.85 **Fe** Iron $[Ar]3d^64s^2$	27 58.93 **Co** Cobalt $[Ar]3d^74s^2$	28 58.69 **Ni** Nickel $[Ar]3d^84s^2$	29 63.55 **Cu** Copper $[Ar]3d^{10}4s^1$	30 65.39 **Zn** Zinc $[Ar]3d^{10}4s^2$	31 69.72 **Ga** Gallium $[Ar]3d^{10}4s^2p^1$	32 72.61 **Ge** Germanium $[Ar]3d^{10}4s^2p^2$	33 74.92 **As** Arsenic $[Ar]3d^{10}4s^2p^3$	34 78.96 **Se** Selenium $[Ar]3d^{10}4s^2p^4$	35 79.90 **Br** Bromine $[Ar]3d^{10}4s^2p^5$	36 83.80 **Kr** Krypton $[Ar]3d^{10}4s^2p^6$
5	37 85.47 **Rb** Rubidium $[Kr]5s^1$	38 87.62 **Sr** Strontium $[Kr]5s^2$	39 88.91 **Y** Yttrium $[Kr]4d^15s^2$	40 91.22 **Zr** Zirconium $[Kr]4d^25s^2$	41 92.91 **Nb** Niobium $[Kr]4d^45s^1$	42 95.94 **Mo** Molybdenum $[Kr]4d^55s^1$	43 (98) **Tc** Technetium $[Kr]4d^55s^2$	44 101.07 **Ru** Ruthenium $[Kr]4d^75s^1$	45 102.91 **Rh** Rhodium $[Kr]4d^85s^1$	46 106.42 **Pd** Palladium $[Kr]4d^{10}$	47 107.87 **Ag** Silver $[Kr]4d^{10}5s^1$	48 112.41 **Cd** Cadmium $[Kr]4d^{10}5s^2$	49 114.82 **In** Indium $[Kr]4d^{10}5s^2p^1$	50 118.71 **Sn** Tin $[Kr]4d^{10}5s^2p^2$	51 121.76 **Sb** Antimony $[Kr]4d^{10}5s^2p^3$	52 127.60 **Te** Tellurium $[Kr]4d^{10}5s^2p^4$	53 126.90 **I** Iodine $[Kr]4d^{10}5s^2p^5$	54 131.29 **Xe** Xenon $[Kr]4d^{10}5s^2p^6$
6	55 132.91 **Cs** Cesium $[Xe]6s^1$	56 137.33 **Ba** Barium $[Xe]6s^2$	♦	72 178.49 **Hf** Hafnium $[Xe]4f^{14}5d^26s^2$	73 180.95 **Ta** Tantalum $[Xe]4f^{14}5d^36s^2$	74 183.84 **W** Tungsten $[Xe]4f^{14}5d^46s^2$	75 186.21 **Re** Rhenium $[Xe]4f^{14}5d^56s^2$	76 190.23 **Os** Osmium $[Xe]4f^{14}5d^66s^2$	77 192.22 **Ir** Iridium $[Xe]4f^{14}5d^76s^2$	78 195.08 **Pt** Platinum $[Xe]4f^{14}5d^96s^1$	79 196.97 **Au** Gold $[Xe]4f^{14}5d^{10}6s^1$	80 200.59 **Hg** Mercury $[Xe]4f^{14}5d^{10}6s^2$	81 204.38 **Tl** Thallium $[Xe]4f^{14}5d^{10}6s^2p^1$	82 207.20 **Pb** Lead $[Xe]4f^{14}5d^{10}6s^2p^2$	83 208.98 **Bi** Bismuth $[Xe]4f^{14}5d^{10}6s^2p^3$	84 (209) **Po** Polonium $[Xe]4f^{14}5d^{10}6s^2p^4$	85 (210) **At** Astatine $[Xe]4f^{14}5d^{10}6s^2p^5$	86 (222) **Rn** Radon $[Xe]4f^{14}5d^{10}6s^2p^6$
7	87 (223) **Fr** Francium $[Rn]7s^1$	88 (226) **Ra** Radium $[Rn]7s^2$	★	104 (265) **Rf** Rutherfordium $[Rn]5f^{14}6d^27s^2$	105 (268) **Db** Dubnium $[Rn]5f^{14}6d^37s^2$	106 (271) **Sg** Seaborgium $[Rn]5f^{14}6d^47s^2$	107 (270) **Bh** Bohrium $[Rn]5f^{14}6d^57s^2$	108 (277) **Hs** Hassium $[Rn]5f^{14}6d^67s^2$	109 (276) **Mt** Meitnerium $[Rn]5f^{14}6d^77s^2$	110 (281) **Ds** Darmstadtium $[Rn]5f^{14}6d^97s^1$	111 (280) **Rg** Roentgenium $[Rn]5f^{14}6d^97s^2$	112 (285) **Cn** Copernicium $[Rn]5f^{14}6d^{10}7s^2$	113 (284) **Uut** Ununtrium $[Rn]5f^{14}6d^{10}7s^27p^1$	114 (289) **Fl** Flerovium $[Rn]5f^{14}6d^{10}7s^27p^2$	115 (288) **Uup** Ununpentium $[Rn]5f^{14}6d^{10}7s^27p^3$	116 (293) **Lv** Livermorium $[Rn]5f^{14}6d^{10}7s^27p^4$	117 (294) **Uus** Ununseptium $[Rn]5f^{14}6d^{10}7s^27p^5$	118 (294) **Uuo** Ununoctium $[Rn]5f^{14}6d^{10}7s^{27}p^6$

♦	57 138.91 **La** Lanthanum $[Xe]5d^16s^2$	58 140.12 **Ce** Cerium $[Xe]4f^15d^16s^2$	59 140.91 **Pr** Praseodymium $[Xe]4f^36s^2$	60 144.24 **Nd** Neodymium $[Xe]4f^46s^2$	61 (145) **Pm** Promethium $[Xe]4f^56s^2$	62 150.36 **Sm** Samarium $[Xe]4f^66s^2$	63 151.96 **Eu** Europium $[Xe]4f^76s^2$	64 157.25 **Gd** Gadolinium $[Xe]4f^75d^16s^2$	65 158.93 **Tb** Terbium $[Xe]4f^96s^2$	66 162.50 **Dy** Dysprosium $[Xe]4f^{10}6s^2$	67 164.93 **Ho** Holmium $[Xe]4f^{11}6s^2$	68 167.26 **Er** Erbium $[Xe]4f^{12}6s^2$	69 168.93 **Tm** Thulium $[Xe]4f^{13}6s^2$	70 173.04 **Yb** Ytterbium $[Xe]4f^{14}6s^2$	71 174.97 **Lu** Lutetium $[Xe]4f^{14}5d^16s^2$
★	89 (227) **Ac** Actinium $[Rn]6d^17s^2$	90 232.04 **Th** Thorium $[Rn]6d^27s^2$	91 231.04 **Pa** Protactinium $[Rn]5f^26d^17s^2$	92 238.03 **U** Uranium $[Rn]5f^36d^17s^2$	93 (237) **Np** Neptunium $[Rn]5f^46d^17s^2$	94 (244) **Pu** Plutonium $[Rn]5f^67s^2$	95 (243) **Am** Americium $[Rn]5f^77s^2$	96 (247) **Cm** Curium $[Rn]5f^76d^17s^2$	97 (247) **Bk** Berkelium $[Rn]5f^97s^2$	98 (251) **Cf** Californium $[Rn]5f^{10}7s^2$	99 (252) **Es** Einsteinium $[Rn]5f^{11}7s^2$	100 (257) **Fm** Fermium $[Rn]5f^{12}7s^2$	101 (258) **Md** Mendelevium $[Rn]5f^{13}7s^2$	102 (259) **No** Nobelium $[Rn]5f^{14}7s^2$	103 (262) **Lr** Lawrencium $[Rn]5f^{14}7s^27p^1$

Aa - Solid
Aa - Gas
Aa - Liquid
Aa - Synthetically Prepared

* Based on Carbon-12. (###) represents most stable or most stable expected isotope.

** Some electron configurations are based on theoretical expected arrangements.

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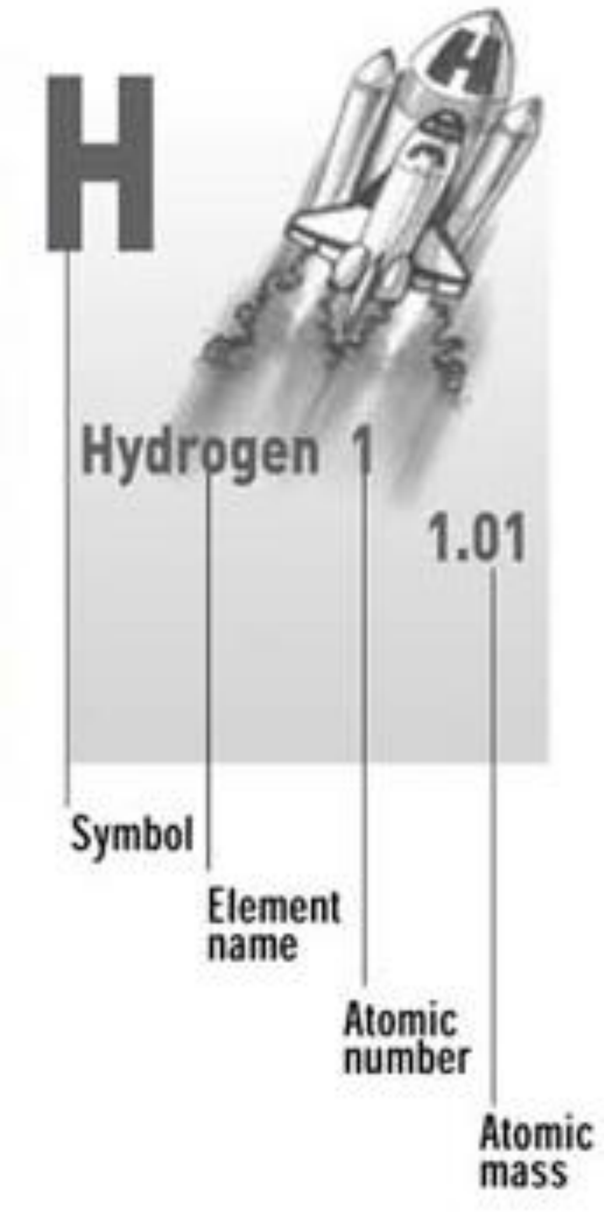


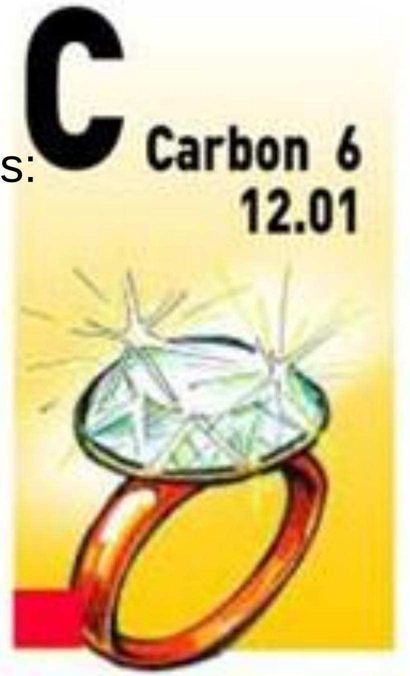
Each different type of atom is called a **nuclide**

Atomic number (Z) = *number of protons*. This defines an **element**

The *number of neutrons* defines an **isotope** of an element

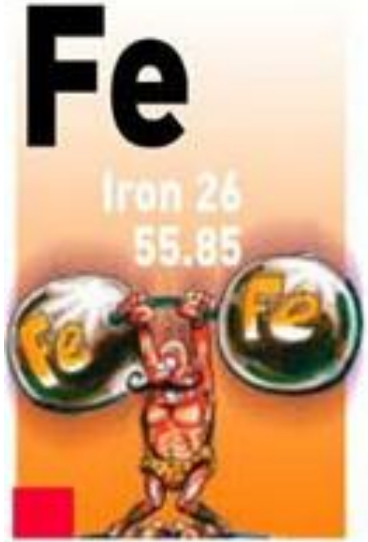
The **atomic mass** (A) is approximately the number of protons + the number of neutrons *but not exactly....*

Binding energy



Carbon 12 has:

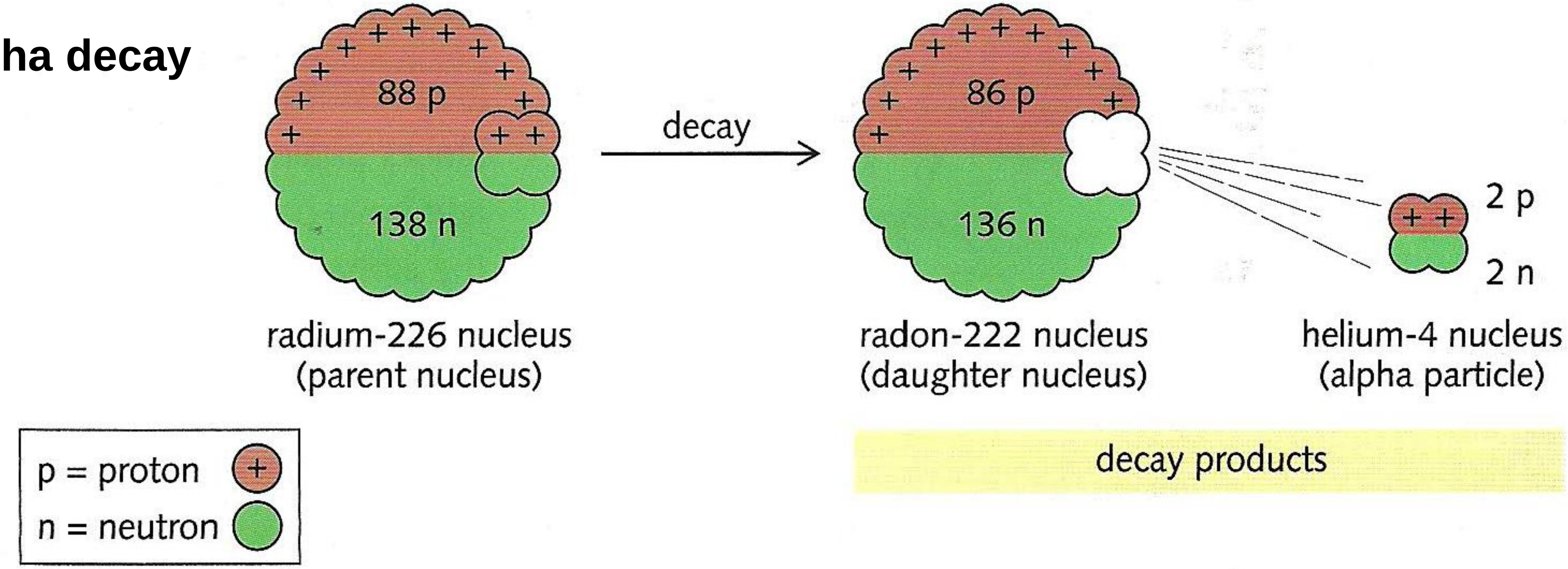
- 6 protons
- 6 electrons
- 6 neutrons



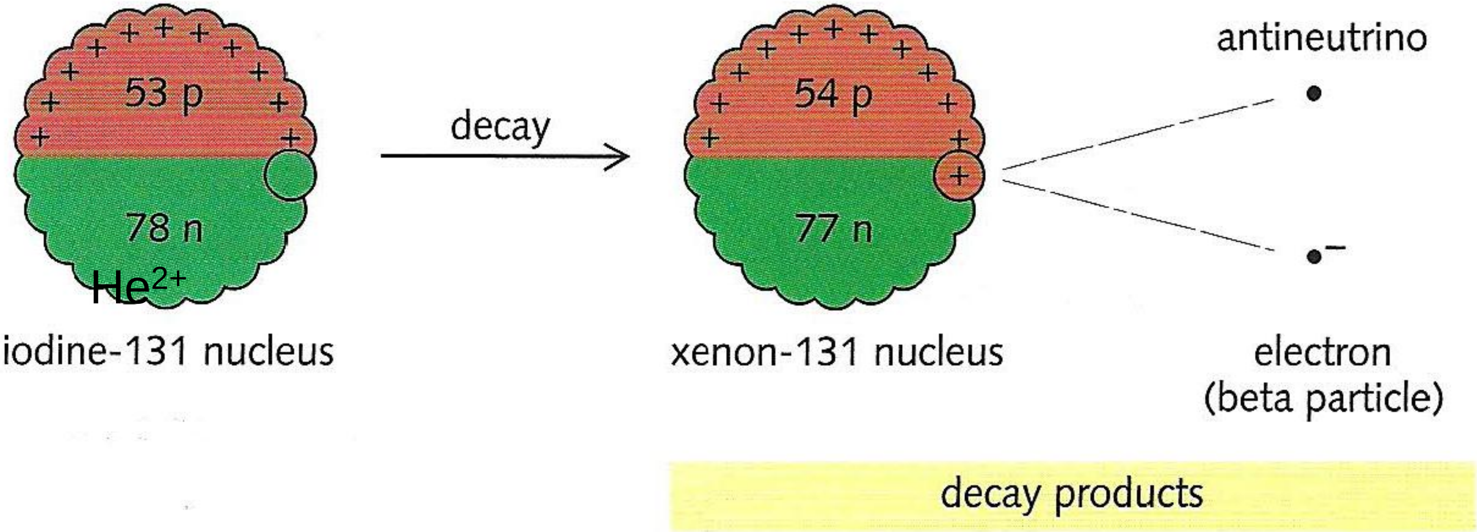
Iron 56 has:

- 26 protons
- 26 electrons
- 30 neutrons

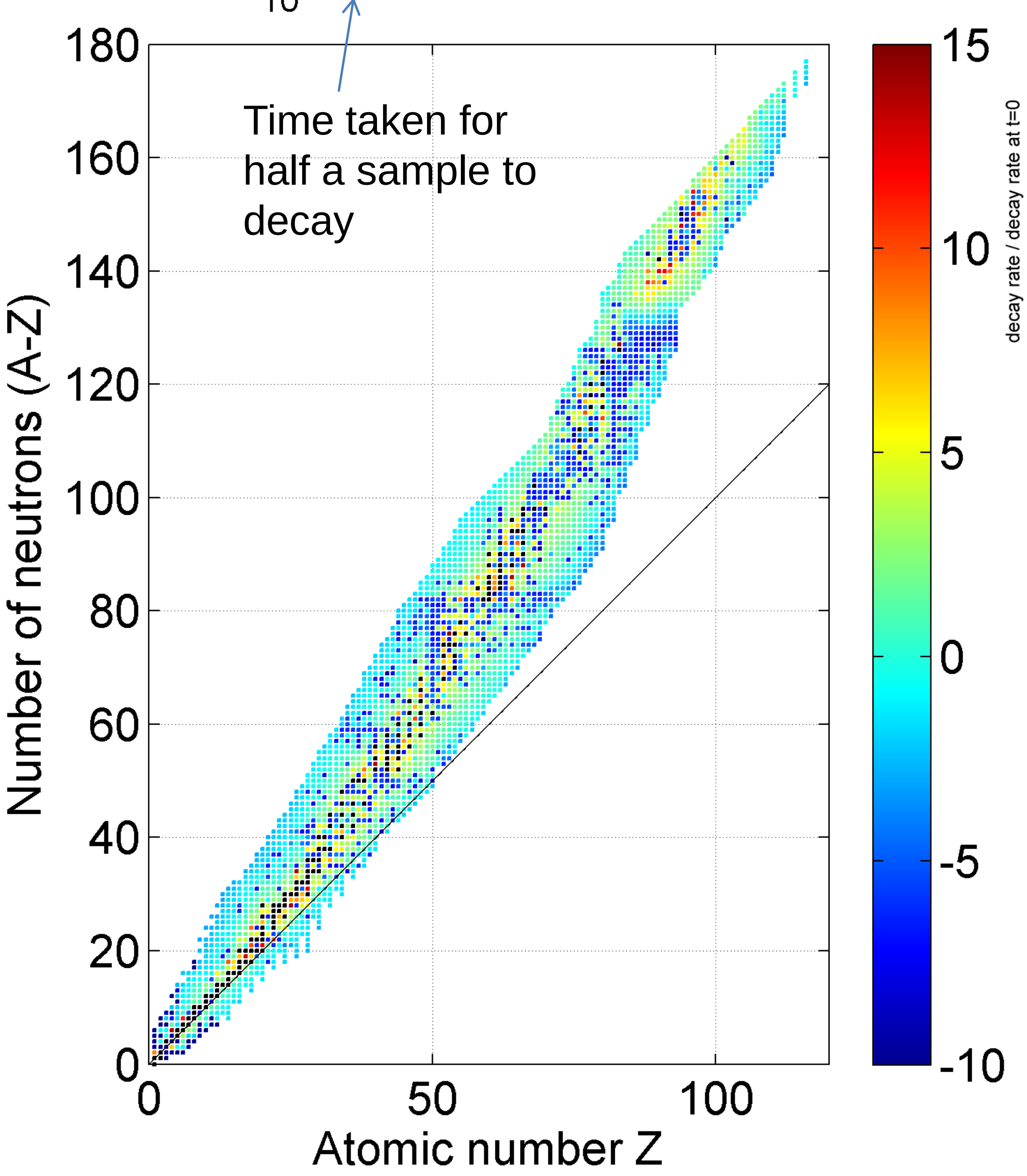
Alpha decay



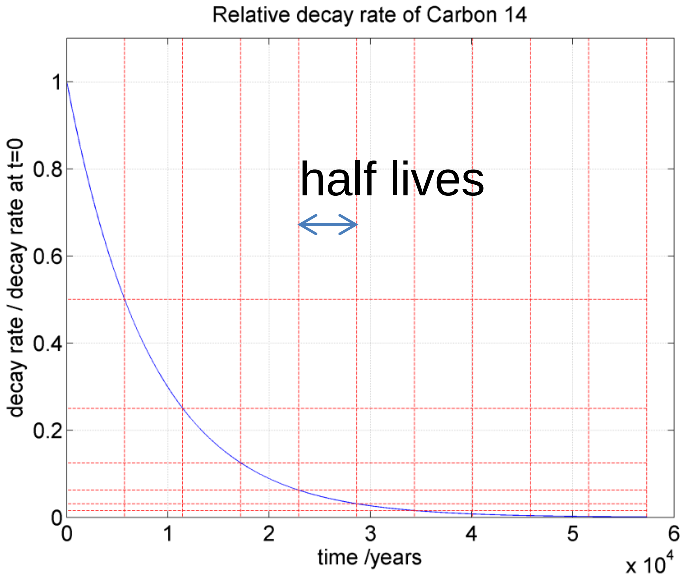
Beta decay



$\log_{10}$(half life /s) for isotopes

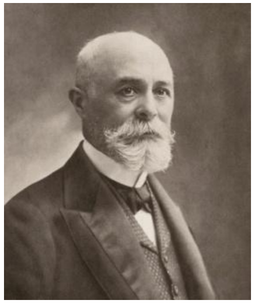


Time taken for half a sample to decay



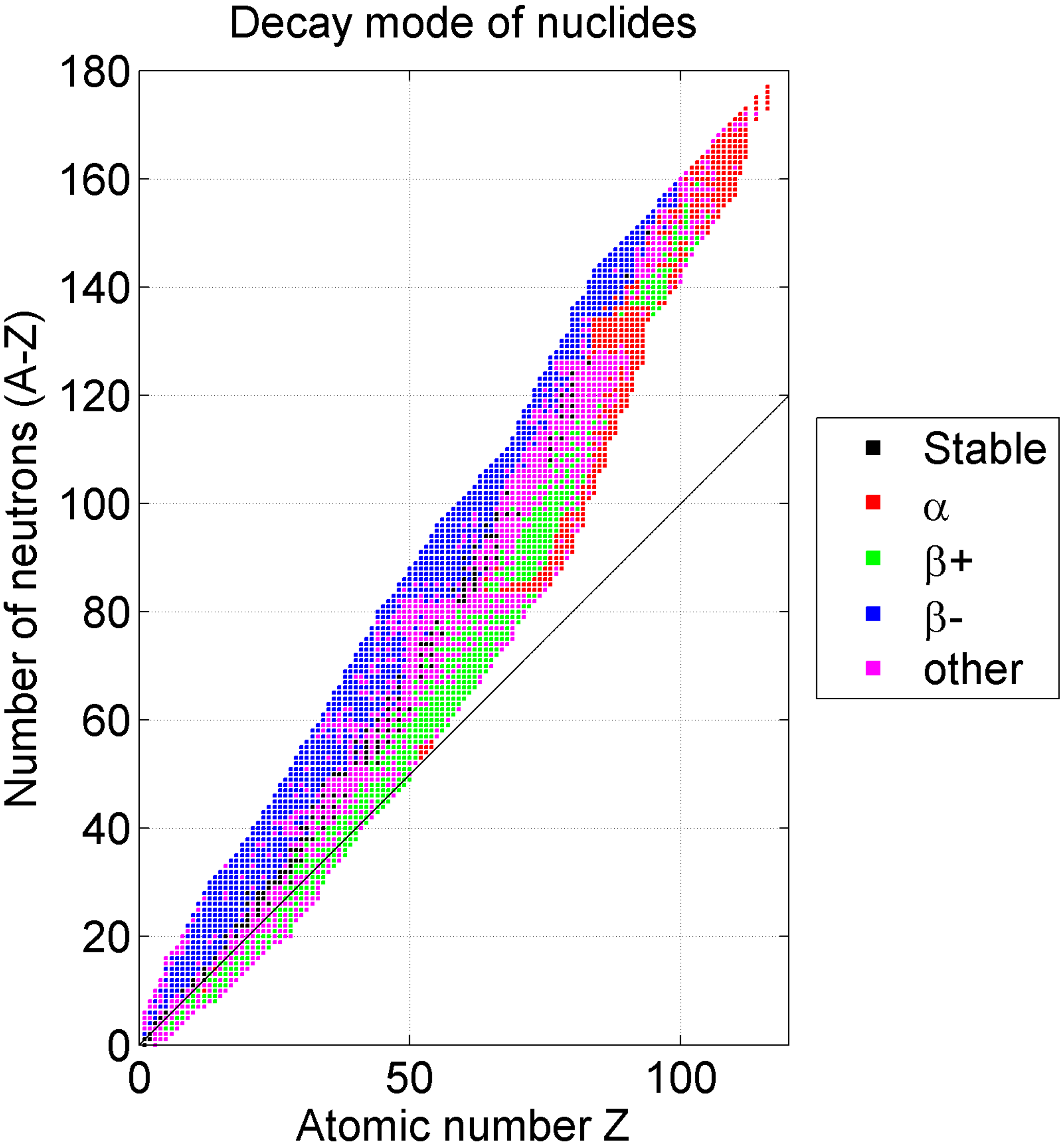
The decay of atomic nuclei is a *random process*

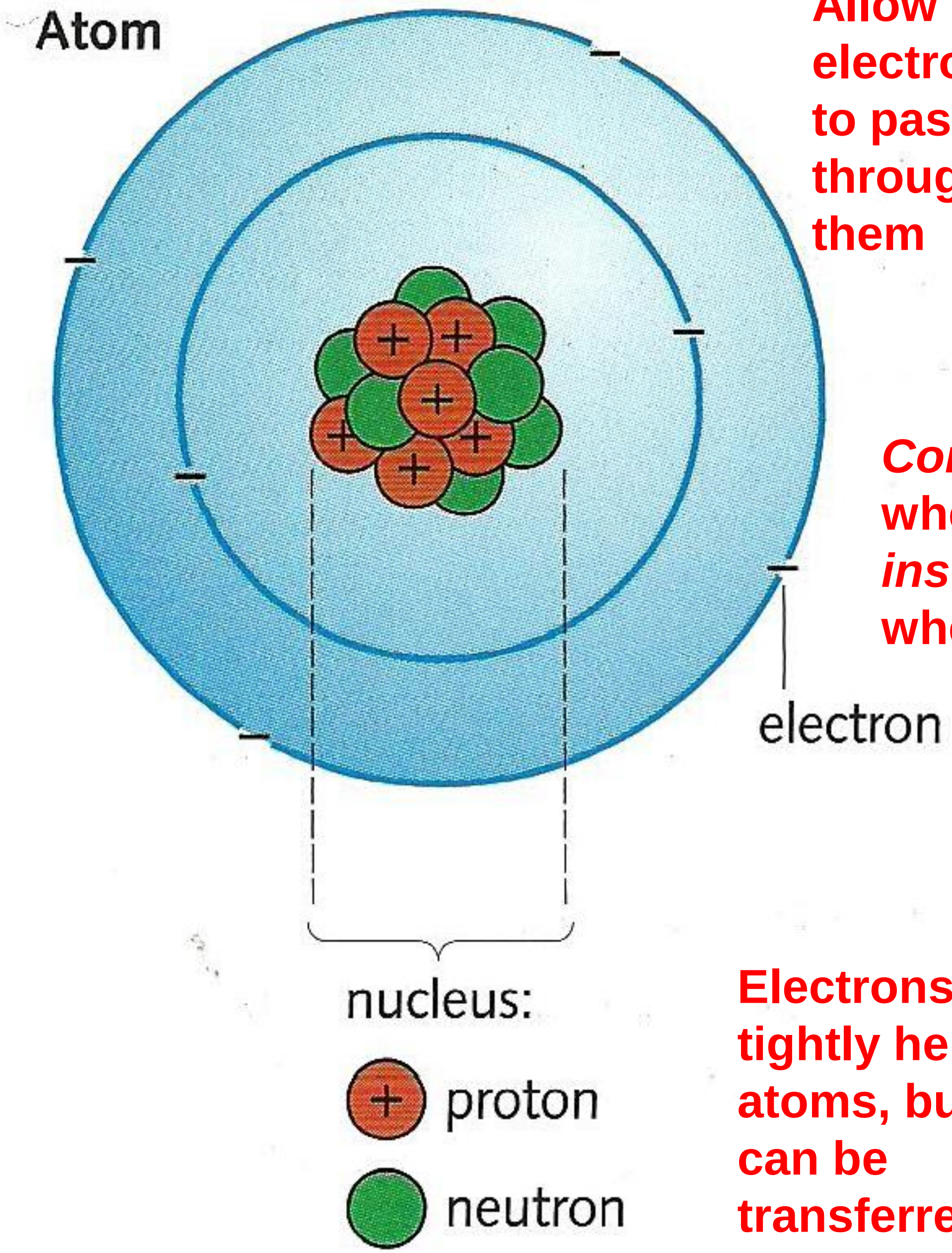
The *decay rate* is proportional to the number of radioactive elements in a sample



Antoine Henri Becquerel
1852-1908
Spontaneous
radioactivity
in Uranium salts

Marie Curie
1867-1934
Theory of radioactivity
Isolation of isotopes





Allow electrons to pass through them

Conductors

Good	Poor
metals	water
especially:	human body
silver	earth
copper	
aluminium	
carbon	

Good thermal conductors

Conductor **when hot** ***insulator*** **when cold**

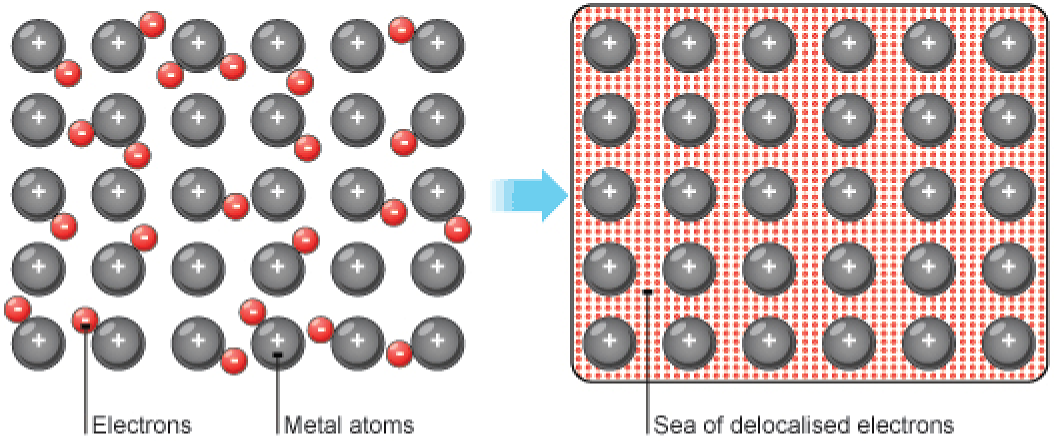
Semiconductors

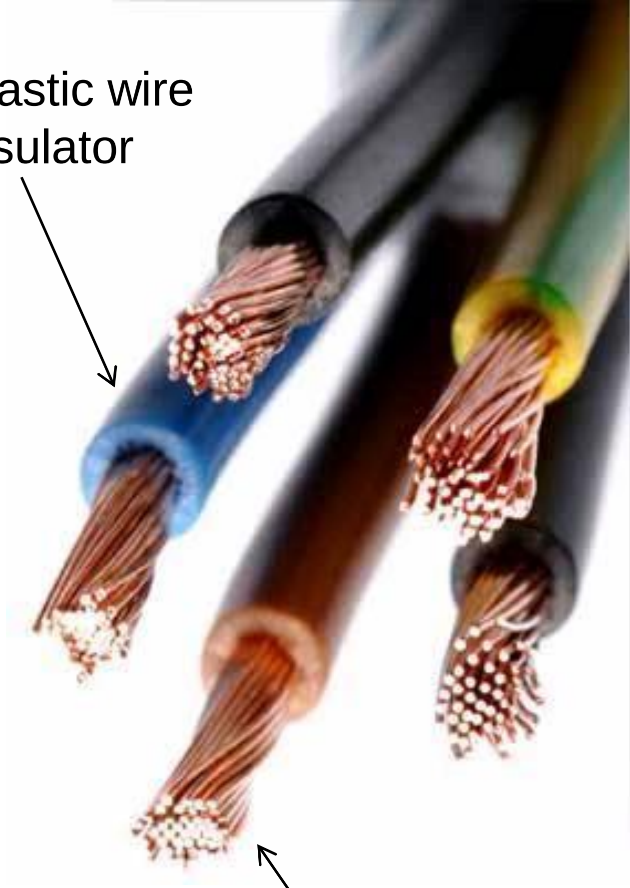
silicon	germanium

Electrons tightly held by atoms, but can be transferred by rubbing

Insulators

plastics	glass
e.g:	rubber
PVC	dry air
polythene	
Perspex	

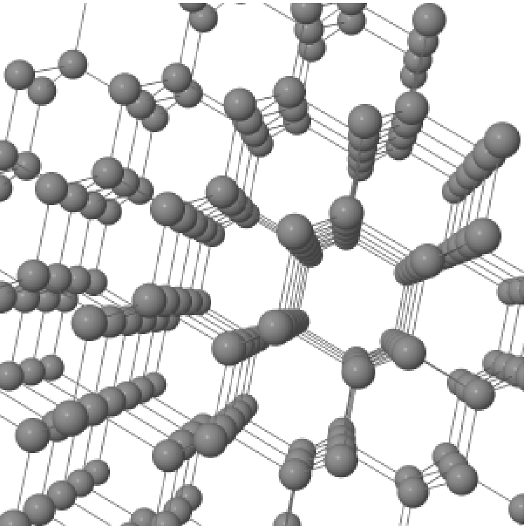


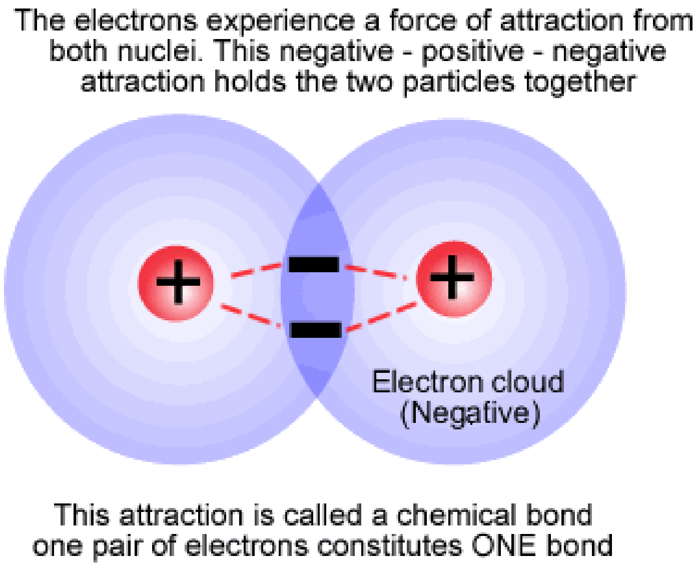


Plastic wire insulator

Metals are good **conductors** as electrons can move easily within them

Insulators (such as plastics) are often polymers formed from a network of **covalent bonds.** It is much harder to extract electrons from them!





The electrons experience a force of attraction from both nuclei. This negative - positive - negative attraction holds the two particles together

This attraction is called a chemical bond one pair of electrons constitutes ONE bond

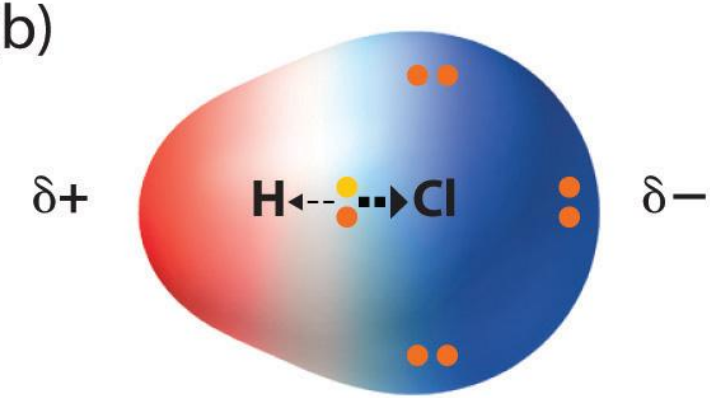
Copper wire. **metallic bonding** of atoms so a good electrical (and heat) conductor

(a)

Nonpolar covalent bond

Bonding electrons shared
equally between two atoms.
No charges on atoms.

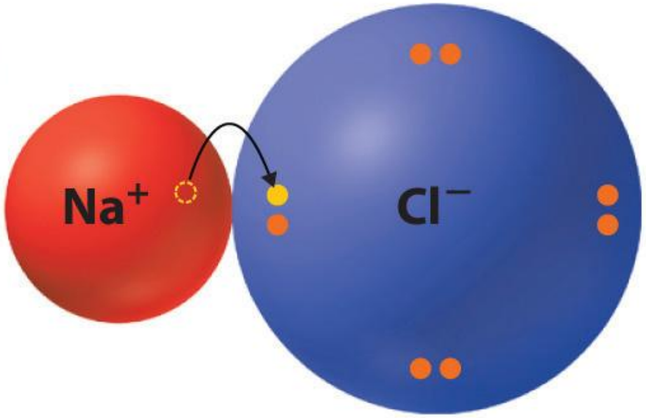
(b)



Polar covalent bond

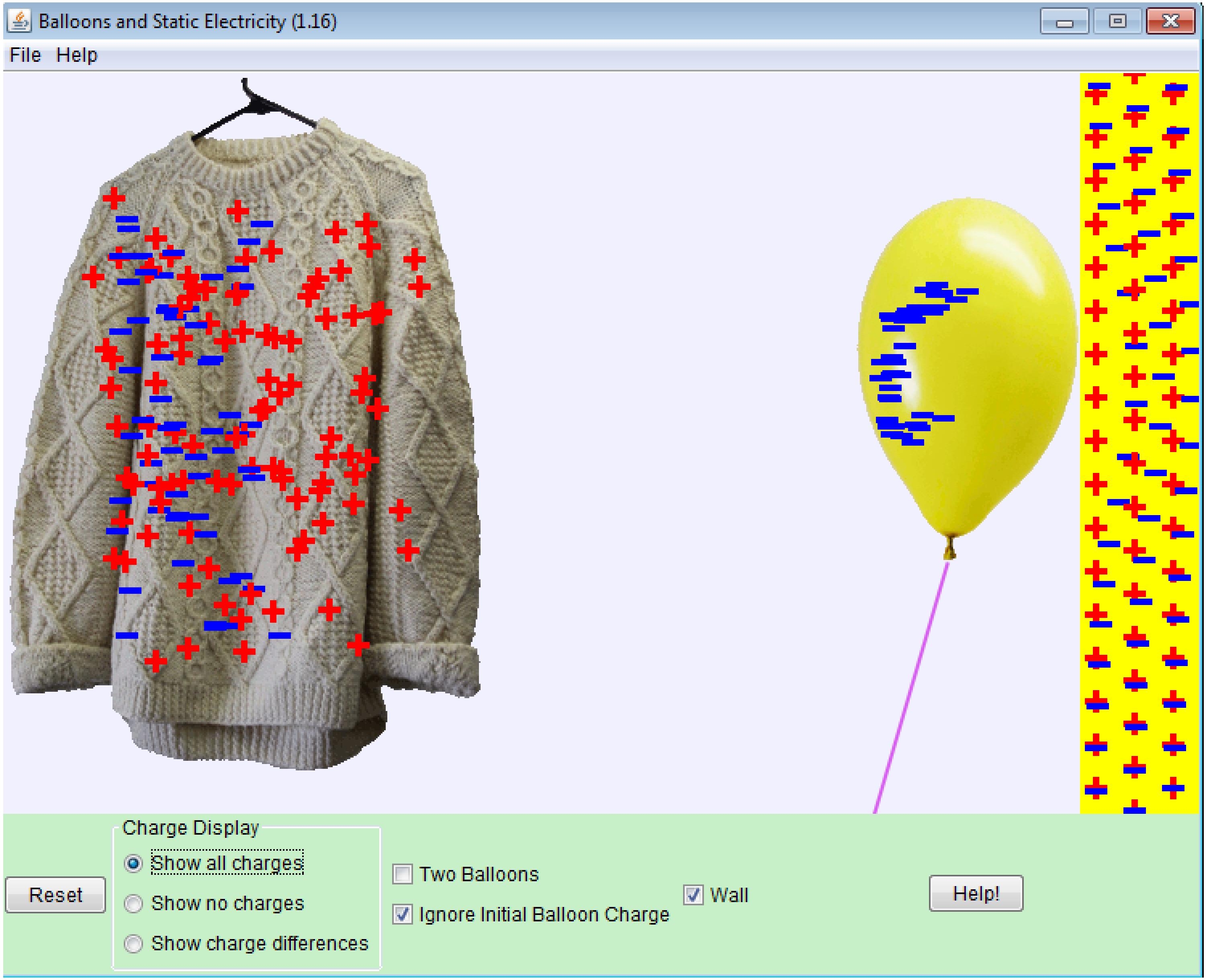
Bonding electrons shared
unequally between two atoms.
Partial charges on atoms.

(c)



Ionic bond

Complete transfer of one or more
valence electrons.
Full charges on resulting ions.



Charge Display

● Show all charges

○ Show no charges

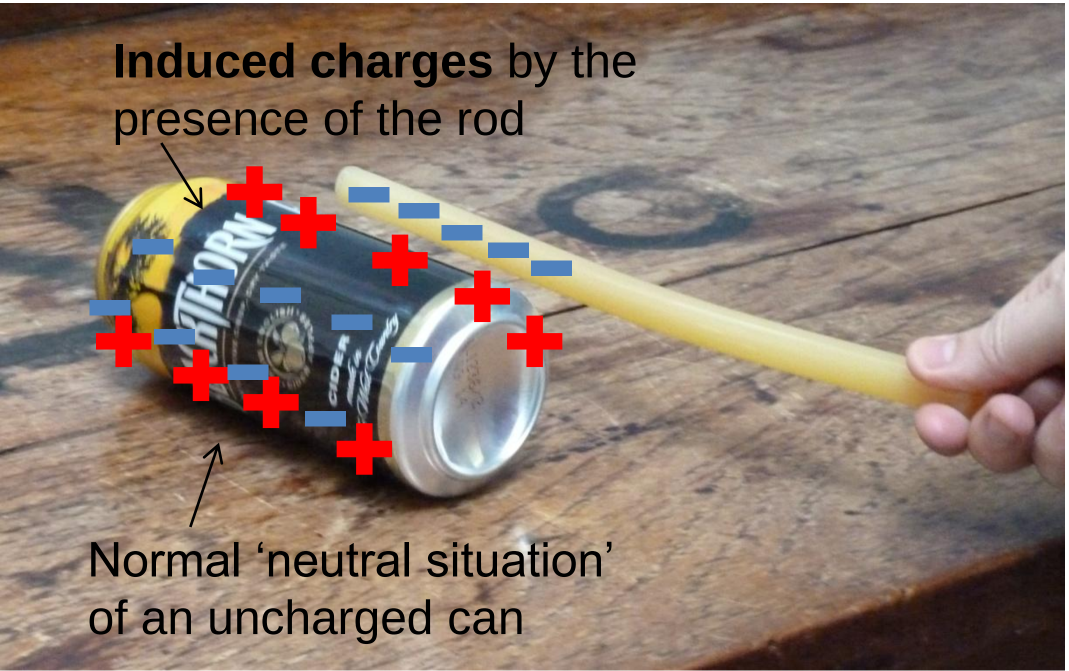
○ Show charge differences

☐ Two Balloons

☑ Ignore Initial Balloon Charge

☑ Wall

‘Walking a can’ with a charged polythene rod



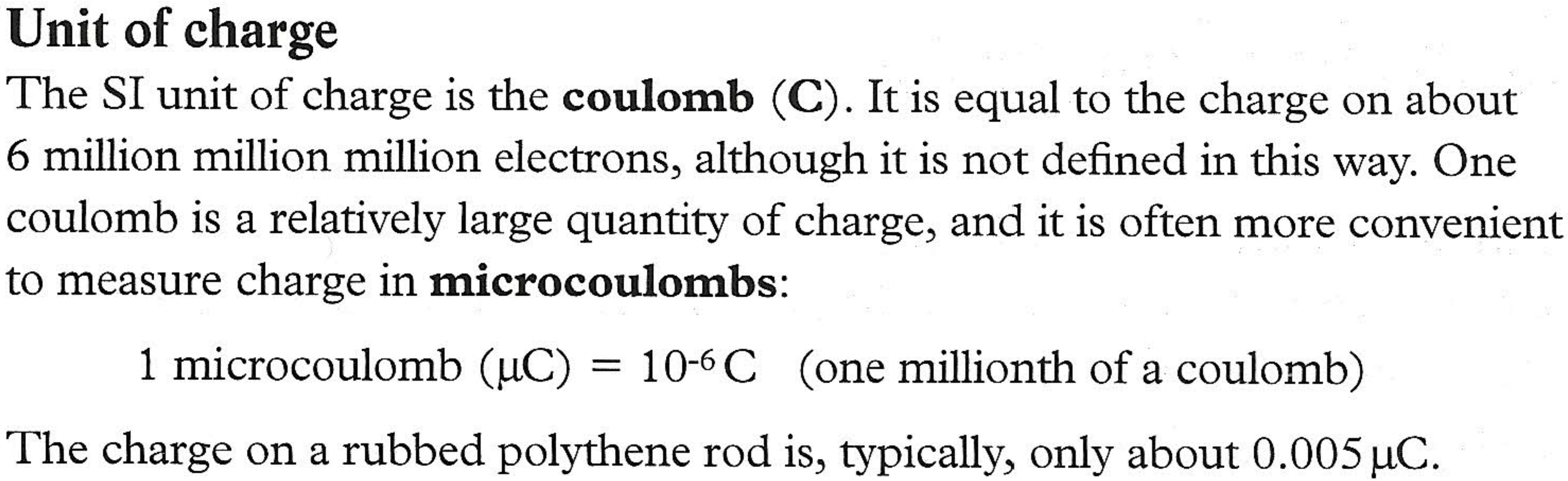
Induced charges by the presence of the rod

Normal ‘neutral situation’ of an uncharged can

Rubbing a polythene rod transfers electrons to it. Polythene is an *insulator* so the charge remains on the surface (rather than flowing to ground if it were a *conductor*).

Placing the negatively charged rod near a metal can will cause the *lightly held electrons* on it to be *repelled*, leaving a *net positive charge.*

The positively charged can will therefore roll *towards* the negatively charged rod.



Unit of charge

The SI unit of charge is the **coulomb** (**C**). It is equal to the charge on about 6 million million million electrons, although it is not defined in this way. One coulomb is a relatively large quantity of charge, and it is often more convenient to measure charge in **microcoulombs**:

1 microcoulomb (μC) = 10^{-6} C (one millionth of a coulomb)

The charge on a rubbed polythene rod is, typically, only about 0.005 μC.

Charge on the electron is *-e*

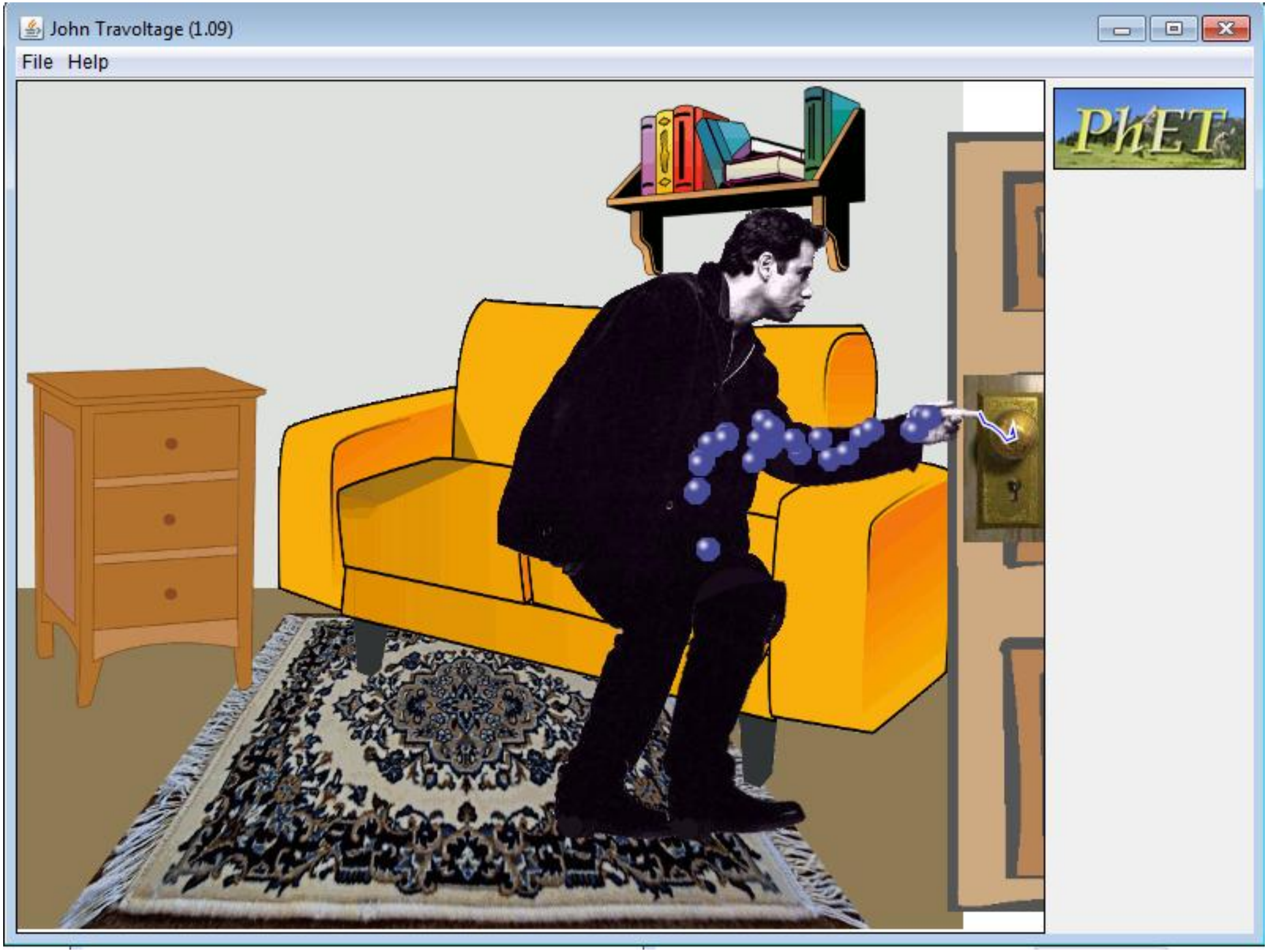
$$e = 1.602 \times 10^{-19}\,\mathrm{C}$$

1 **amp** means 1 coloumb of charges flows per second

$$Q = It$$

Q charge
I current
t time

Charles-Augustin de Coulomb
1736-1806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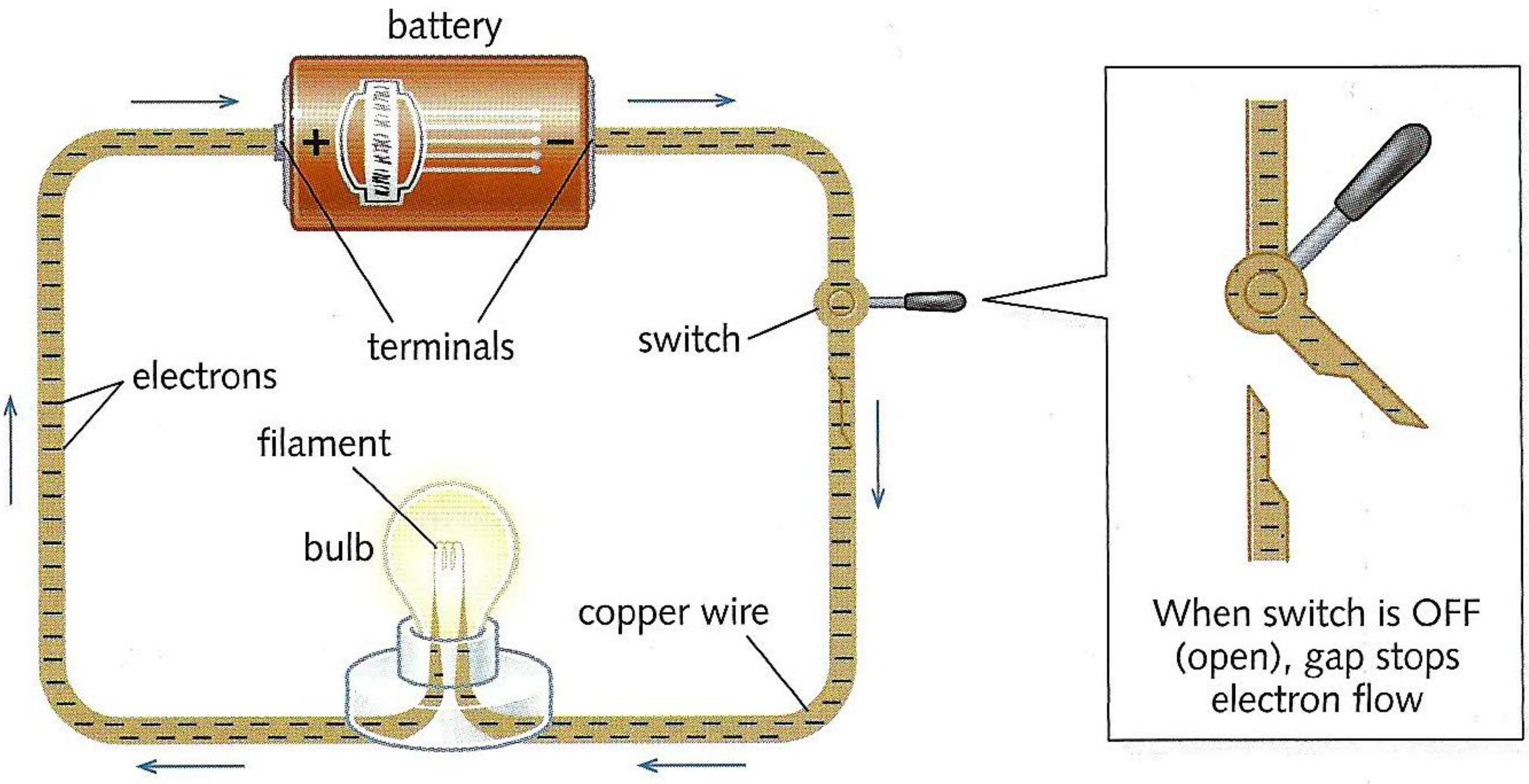
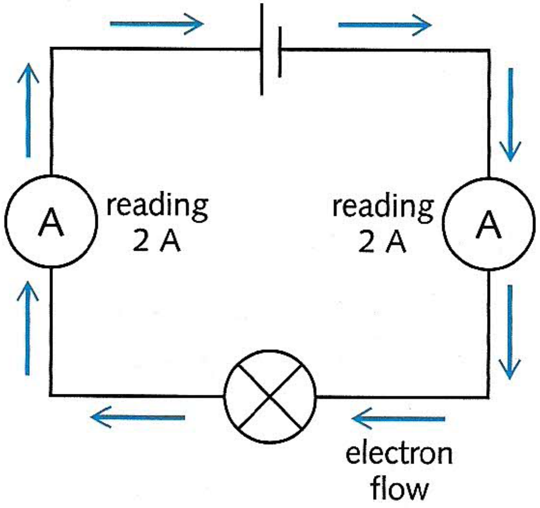
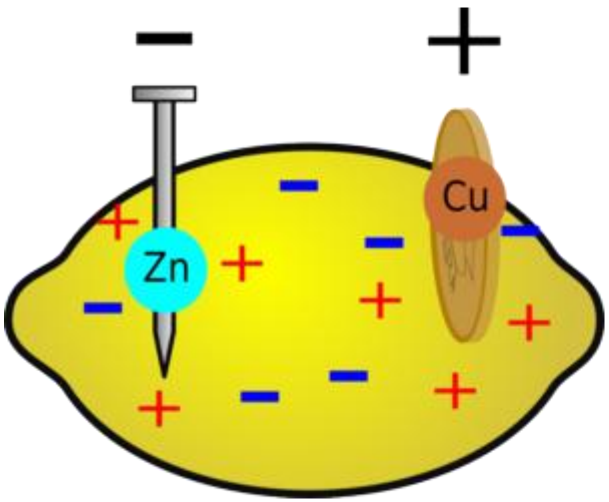


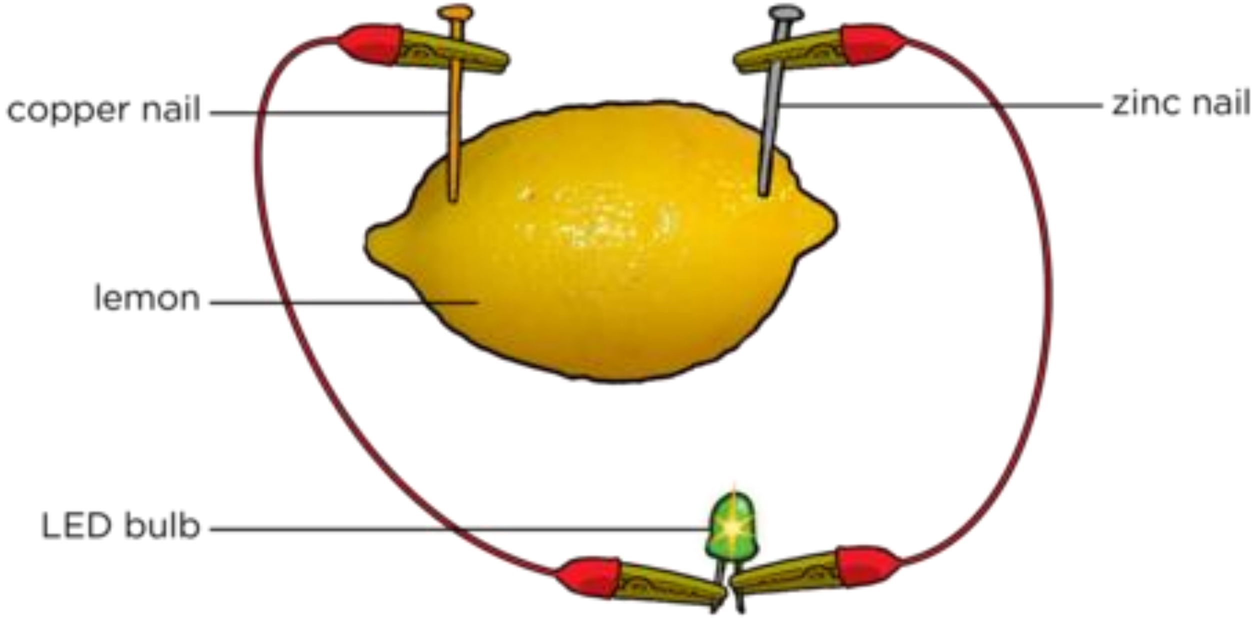
1 **amp** means 1 coloumb of charges flows per second

$$Q = It$$



Make a lemon battery

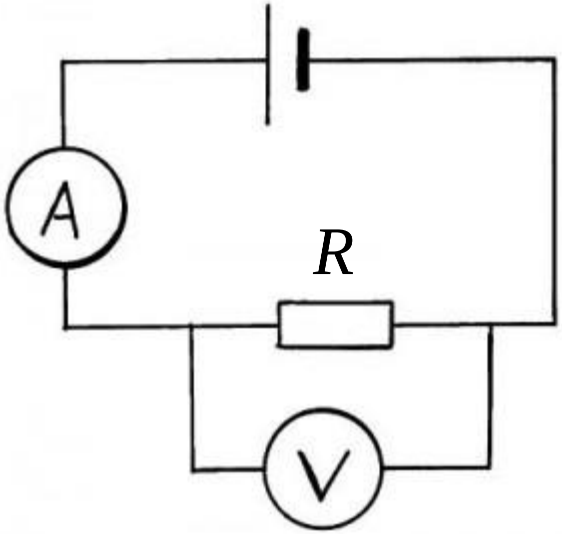




*German School Teacher

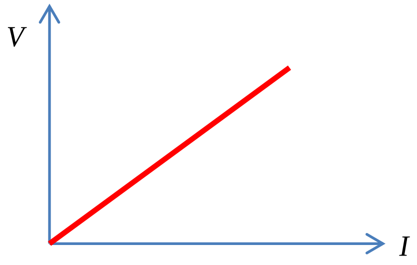
Georg Ohm*

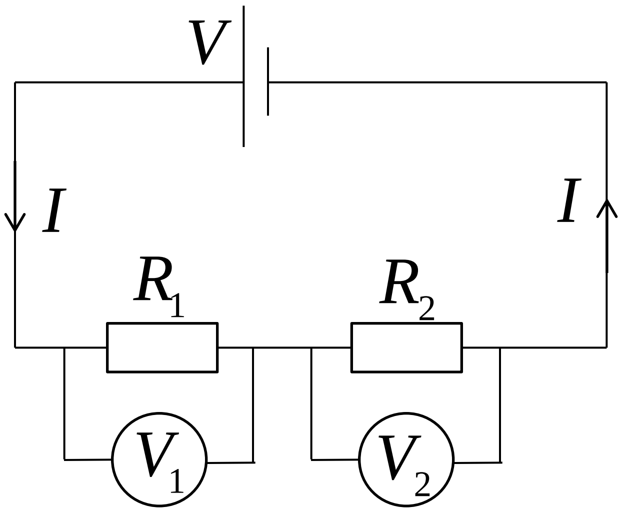
1789-1854



$$\boxed{V = IR}$$

Ohm's Law





The *same* current must flow through every component in the loop, otherwise charge would be created or lost!

$$V = IR$$

Apply Ohm's law to entire series loop. *R* is the total resistance

$$V_1 = IR_1$$

$$V_2 = IR_2$$

Apply Ohm's law to each resistor in turn

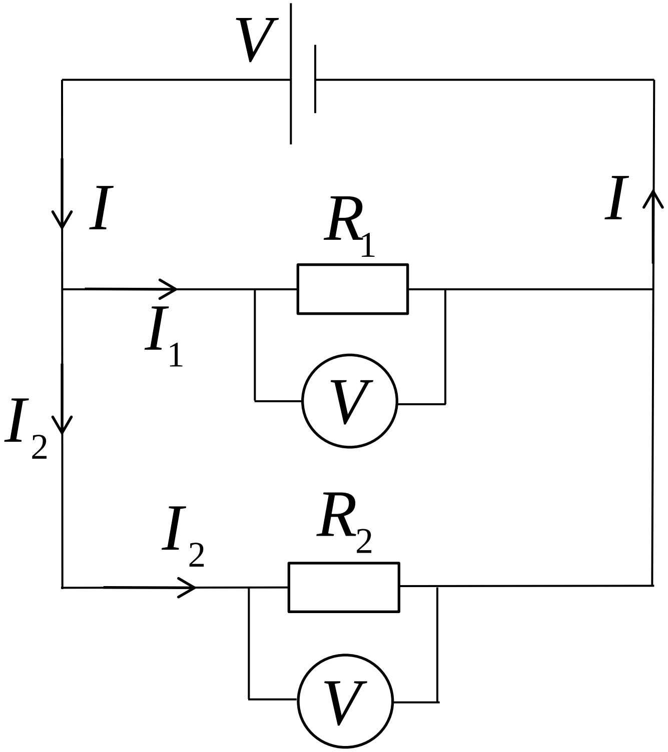
$$V = V_1 + V_2$$

The applied voltage *V* must be divided across the resistors, since this relates to the total energy supplied per unit charge moved

Hence: $$IR = IR_1 + IR_2$$

$$\therefore \boxed{R = R_1 + R_2}$$

so **series** resistors ***add***



$$V = IR$$

Apply Ohm's law to entire circuit. *R* is the total resistance

$$V = I_1 R_1$$

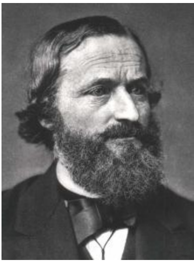
$$V = I_2 R_2$$

Apply Ohm's law to each resistor in turn. Same electric field across each loop, so ***same voltage dropped*** across the resistors

Current is assumed to be contained within the circuit, hence:

$$I = I_1 + I_2$$

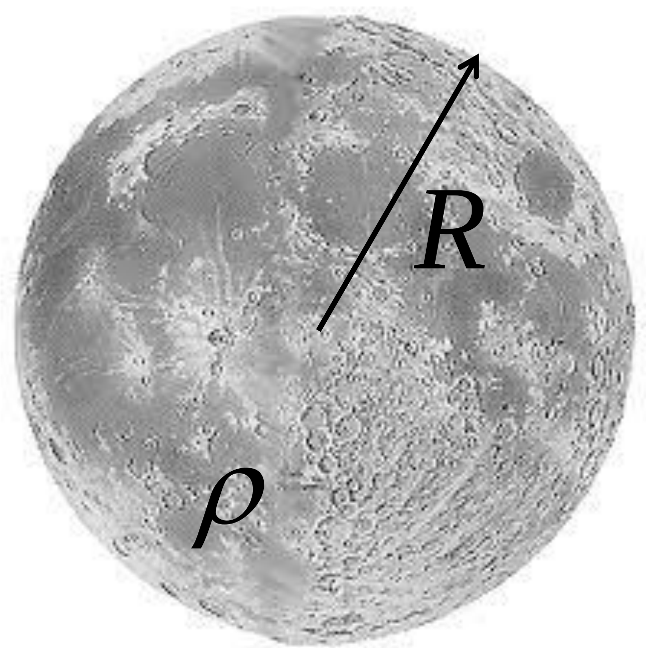
This is *Kirchoff's law*



Therefore: $$V / R = V / R_1 + V / R_2$$

$$\therefore \boxed{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}}$$

so **parallel** resistor loop resistance ***reciprocals*** add



Newton's law of universal gravitation states that the gravitational field strength at a distance *R* from a spherical object is proportional to the mass contained within a sphere of radius *R* centred on the object and inversely proportional to R^2

$$\boxed{g = \frac{GM}{R^2}}$$

$G = 6.67 \times 10^{-11}\ \mathrm{m^3\ kg^{-1} s^{-2}}$

If a planet has *uniform density* ρ

$$\boxed{M = \tfrac{4}{3}\pi R^3 \rho}$$

$$\therefore g = \frac{G}{R^2}\tfrac{4}{3}\pi R^3 \rho$$

$$\Rightarrow \boxed{g = \tfrac{4}{3}\pi G \rho R}$$

$R_{moon} = 1.737 \times 10^6\,\mathrm{m}$

$g_{moon} = 1.63\mathrm{ms^{-2}}$

$\rho = 3359\,\mathrm{kgm^{-3}}$

$R_{earth} = 6.371 \times 10^6\,\mathrm{m}$

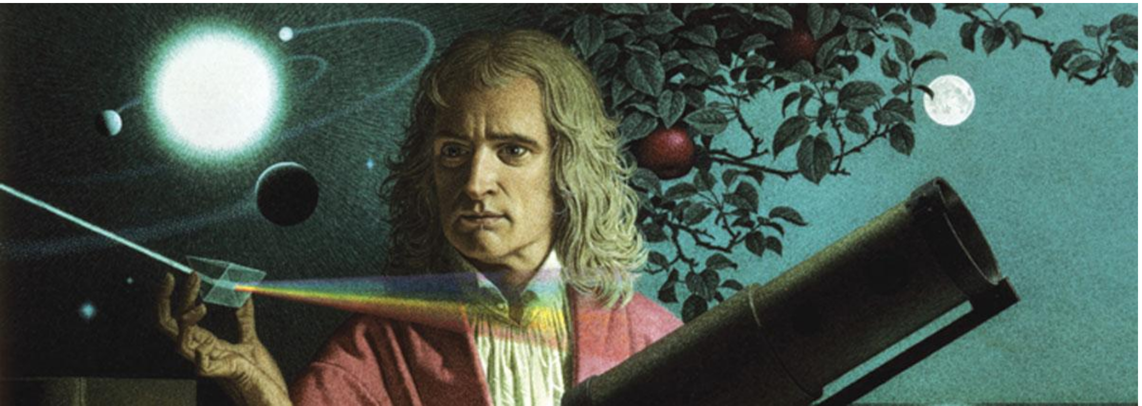
$g_{earth} = 9.81\mathrm{ms^{-2}}$

$\therefore \rho = 5511\mathrm{kgm^{-3}}$

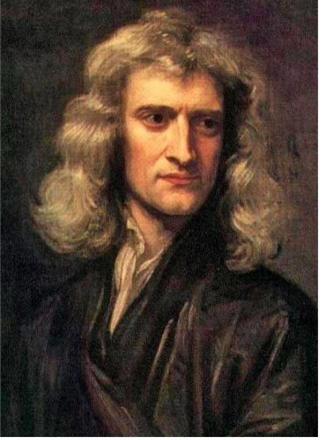
$R_{moon} = 1.737 \times 10^6\,\mathrm{m}$

$g_{moon} = 1.63\mathrm{ms^{-2}}$

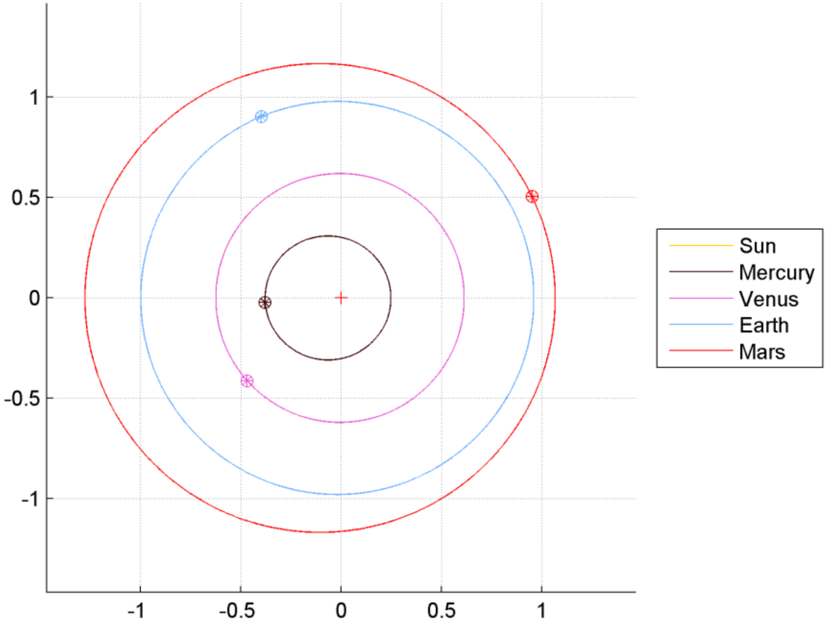
$\therefore \rho = 3359\,\mathrm{kgm^{-3}}$



Isaac Newton
1643-1727



Isaac Newton (1642-1727) developed a mathematical model of Gravity which predicted the elliptical orbits proposed by Kepler



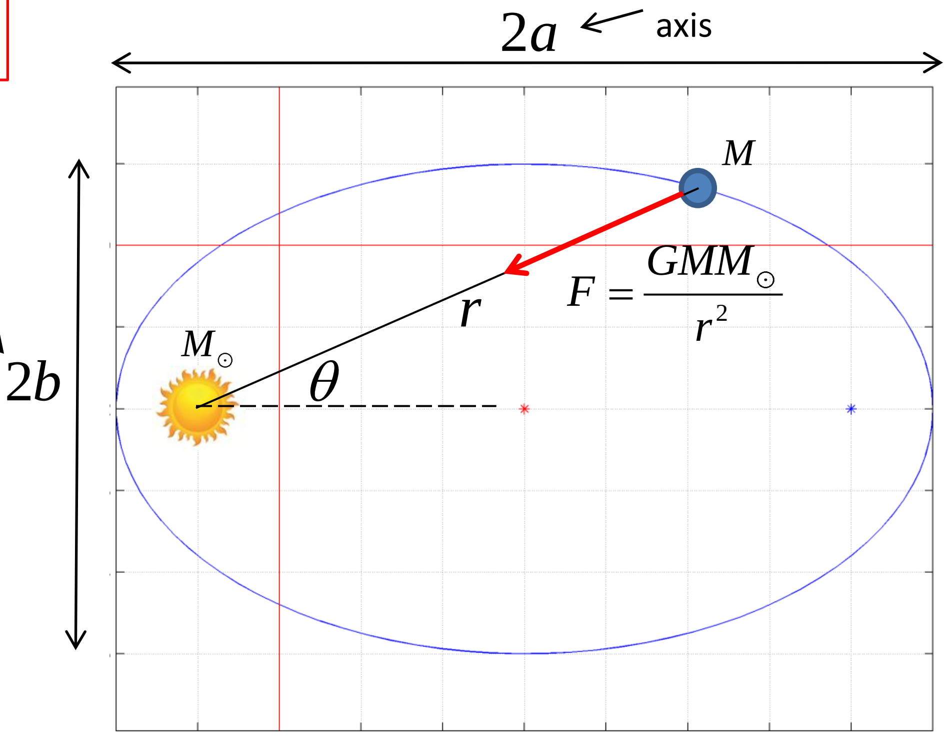
Planet and Solar masses

Force of gravity

$$F = \frac{GMM_{\odot}}{r^2}$$

$$G = 6.67\times10^{-11}\,\mathrm{m}^3\mathrm{kg}^{-1}\mathrm{s}^{-2}$$

Semi-major axis



$$r = \frac{a\left(1-\varepsilon^2\right)}{1+\varepsilon\cos\theta}$$

Polar equation of ellipse

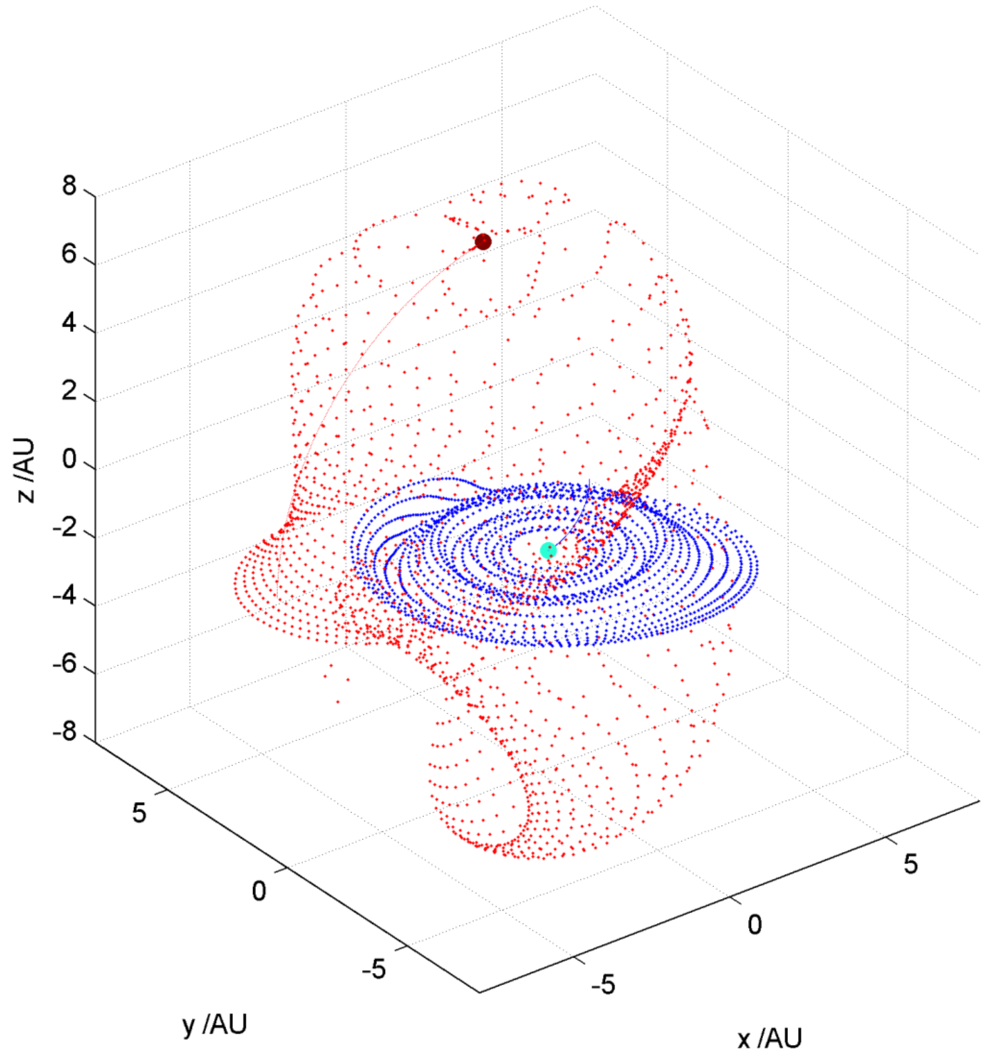
$$\varepsilon = \sqrt{1-\frac{b^2}{a^2}}$$

Eccentricity of ellipse

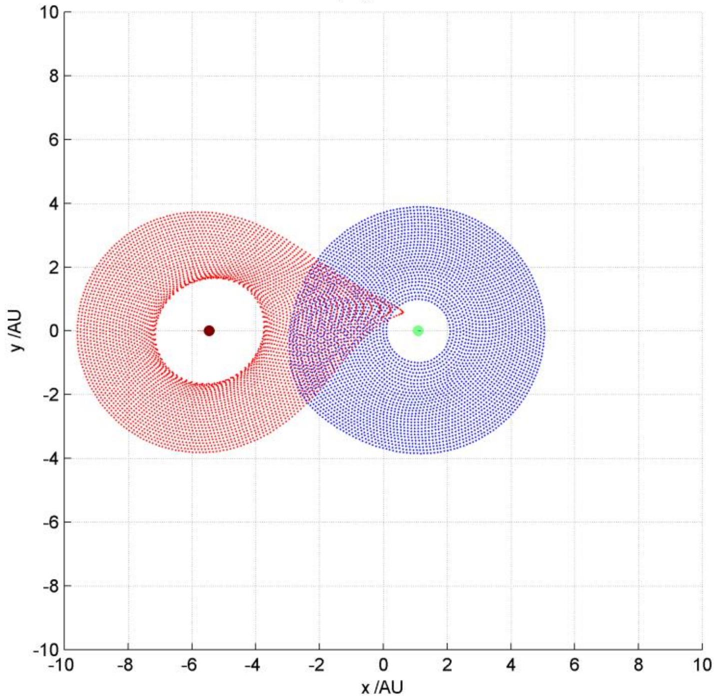
$$P^2 = \frac{4\pi^2}{G(M+M_{\odot})}a^3$$

Semi-minor axis

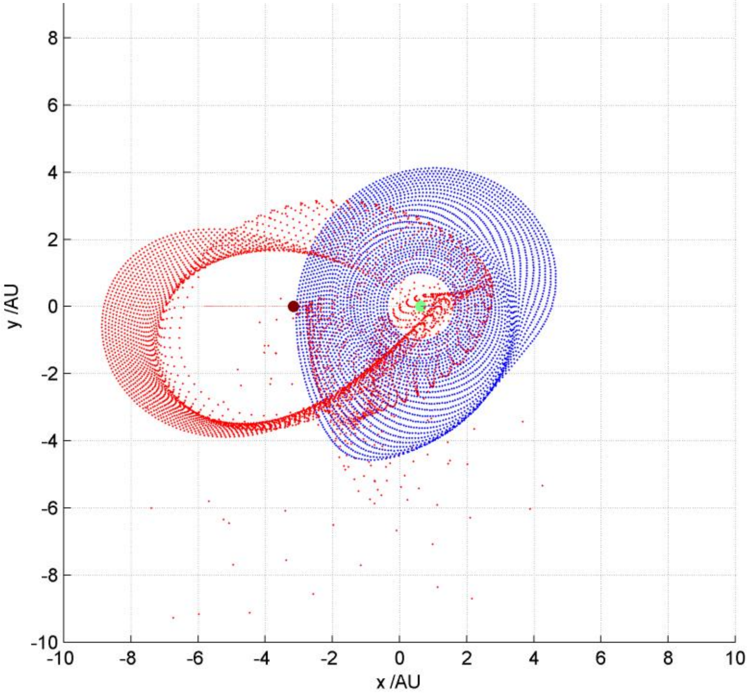
Orbital period *P*



Gravity sim: M_1/M_2 = 0.2. t = 2.79 years.



Gravity sim: M_1/M_2 = 0.2. t = 0.43 years.



Topics to reflect on:

Length scales. Size of an atomic nucleus, atom, molecule, virus, bacteria, cell, human, county, country, Earth, Star, Solar System, Galaxy, Universe!

Atoms, electrons, neutrons, protons, quarks ...

Forces: Nuclear (**strong**, **weak**), **Electrical**, **Gravity**

Periodic table. Atomic numbers. Radioactivity

Electrical forces, **charge** and **electricity**

Effects of **gravity** and **orbits**

Depending on your course, we may not cover all of these. Review the topics you did meet. If you have time to spare, read on!