Electric Charges, Forces and Fields

Chapter 17

- Forces of Nature
- Electric Charge
- Coulomb’s Law
- Electric Field
- Electric Field Lines
- Flux of an Electric Field

Part 1

Forces of nature
or
A short journey …
back to Physics 111

Physics 111: Analysis of motion - 3 key ideas

Newton's laws of motion

Conservation of Energy

Conservation of Momentum

Newton's laws of motion

Newton's First Law: If no force acts on a body, then the body's velocity cannot change

Newton's Second Law: $\boxed{\vec{F} = m\vec{a}}$

Newton's laws of motion allow us to analyze many kinds of motion.

Newton's laws of motion (applications)

Special case: motion with **constant** acceleration (1D, 2D or 3D motion)

$$\boxed{\vec{F} = m\vec{a}}$$

$$\downarrow$$

$$\boxed{\begin{aligned} x &= x_0 + v_0 t + \frac{at^2}{2} \\ v &= v_0 + at \end{aligned}}$$

Observables:

time
position
velocity
acceleration

force

Examples of problems: projectile motion, …

Conservation of energy

The total energy of an isolated system cannot change

In an isolated system where only conservative forces cause energy changes, the kinetic energy and potential energy can change, but their sum cannot change

$$K_i + U_i = K_f + U_f$$

Conservation of momentum

Conservation of linear momentum

If no net external force acts on a system of particles, the total linear momentum of the system cannot change

$$\vec{P} = m_1\vec{v}_1 + m_2\vec{v}_2 + \ldots + m_n\vec{v}_n = const$$

Conservation of angular momentum

If the net external torque acting on a system is zero, the angular momentum of the system remains constant, no matter what changes take place within the system

$$\vec{L}_i = \vec{L}_f$$

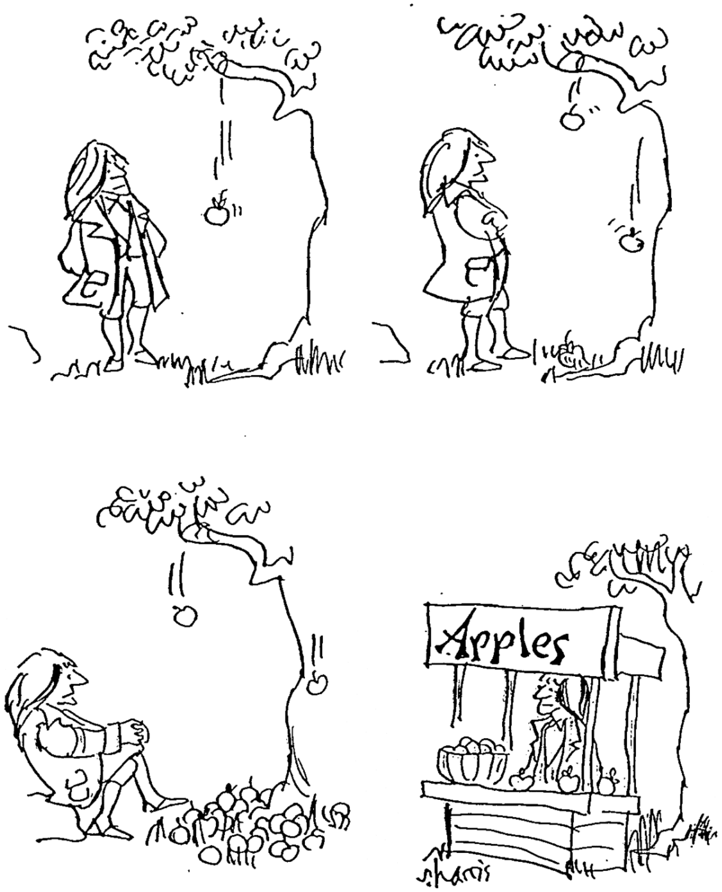
What forces do we know from our experience and Physics 111?

Gravitational Force

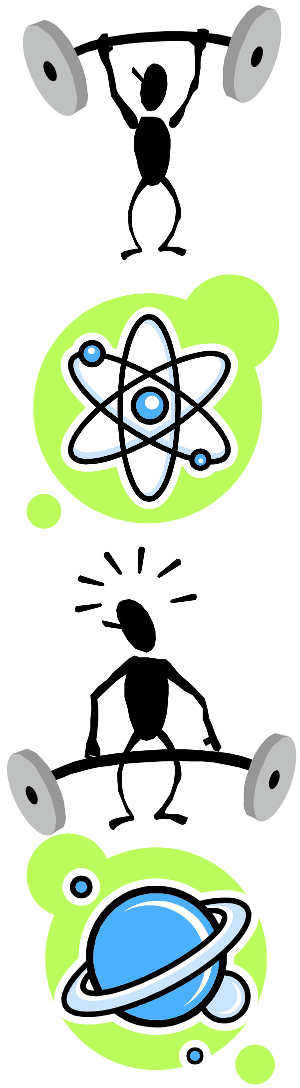
Frictional Force

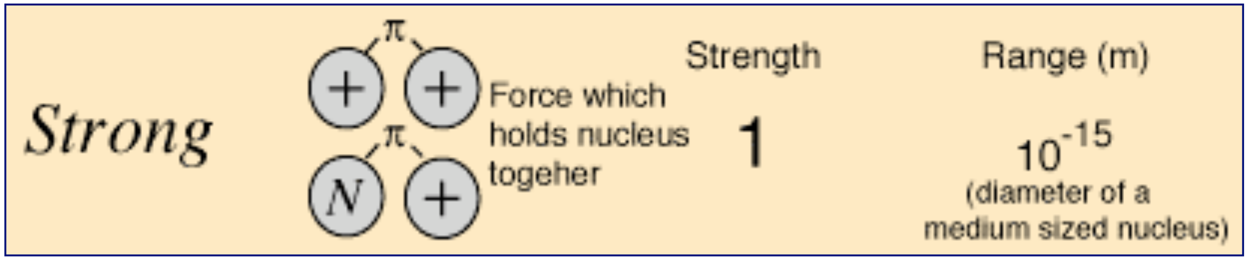
Spring Force (Hook's Law)

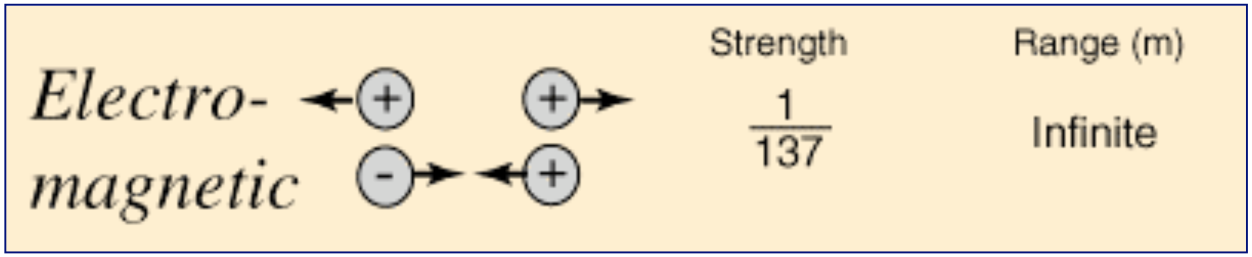
Tension force in a string……

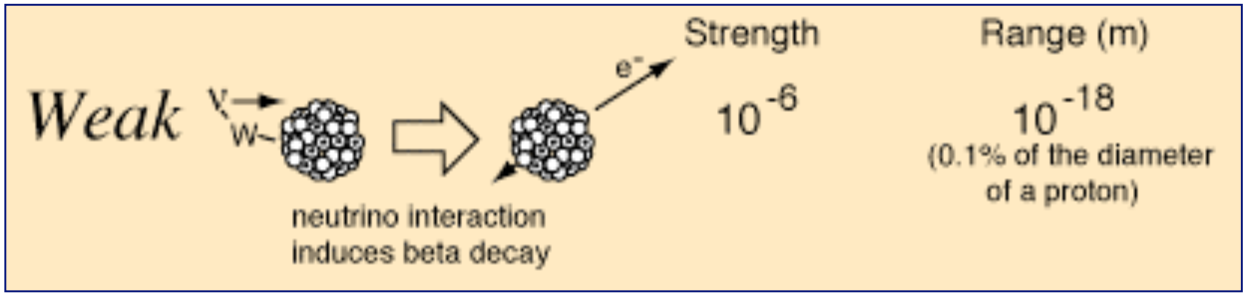


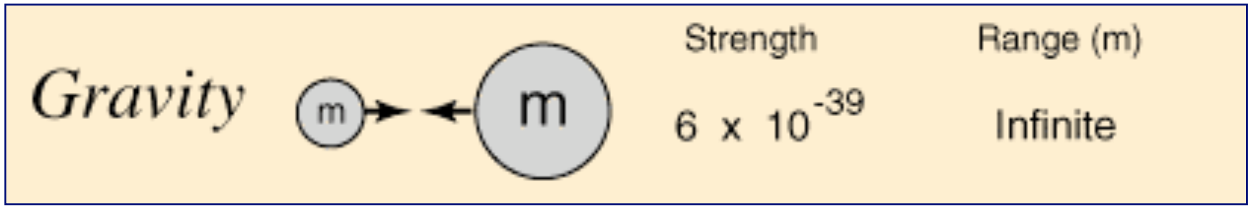
There are ONLY four fundamental forces of nature



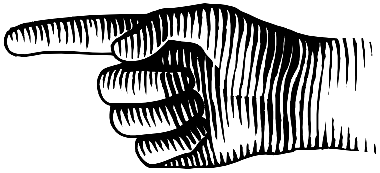








FOUR or ONE?



Many scientists think that all four of the fundamental forces are, the manifestations of a single force which has yet to be discovered.

Just as electricity, magnetism, and the weak force were unified into the electroweak interaction, they work to unify all of the fundamental forces.

Gravitational and electro-magnetic forces: this is what we experience!!!

Travis Morisse / The Hutchinson News

Part 2

Electric Charge

Electric charge

Electric Charge is an intrinsic characteristic of the fundamental particles making up objects around us (including us).

The ordinary matter consists of three (only!) particles:

	electron (e)	proton (p)	neutron (n)
mass	9.11×10^{-31} kg	1.67×10^{-27} kg	1.67×10^{-27} kg
charge	-1.60×10^{-19} C	1.60×10^{-19} C	0.00

The SI unit of electric charge is the Coulomb

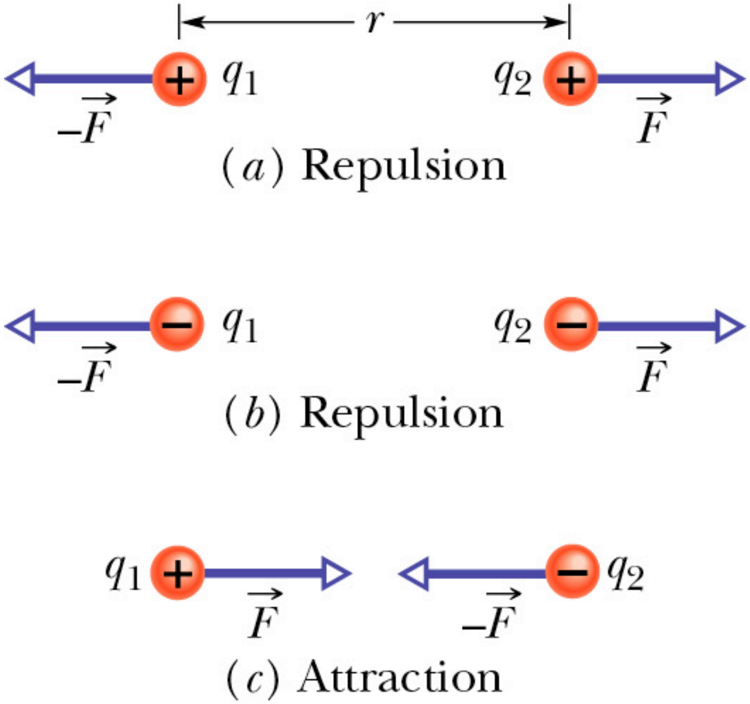
Important characteristic of electric charge

An electric charge has a magnitude and sign.

It is either positive or negative.

Electron has negative electric charge

Proton has positive electric charge

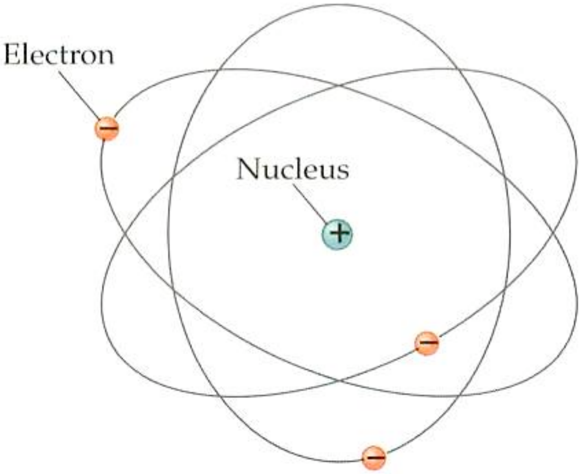


If the charges have the same sign, the forces between them are repulsive

Charges of opposite sign experience attractive forces

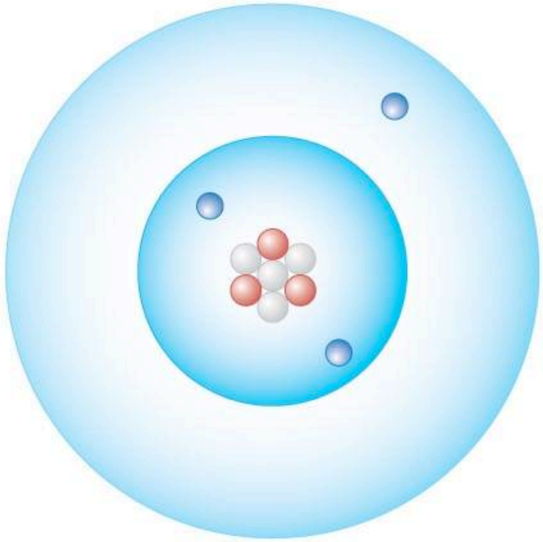
Atoms and molecules are made up from electrons, protons and neutrons!

A classical (solar system) model of an atom (Lithium)



Atoms are combinations of equal amounts of electrons and protons.

A quantum model of an atom (Lithium)



(a) Neutral lithium atom (Li):

3 protons (3+)

4 neutrons

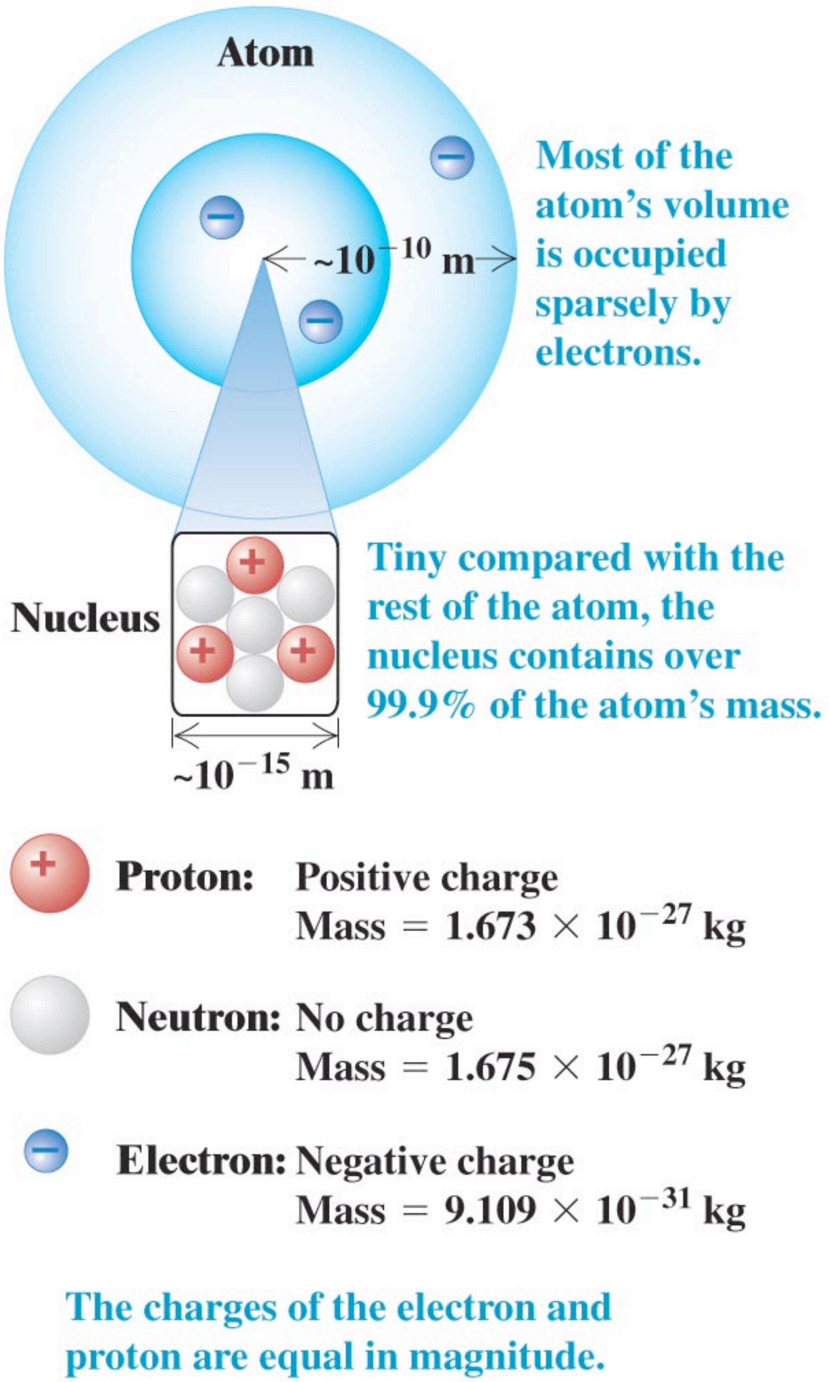
3 electrons (3−)

Electrons equal protons:
Zero net charge

Sizes and masses

Atoms are combinations of equal amounts of electrons and protons. The neutrons provide the glue to stick together the protons in the nucleus.
The proton and the neutron are about 2000 times heavier than the electron, so the vast majority of an atom's mass resides in the nucleus.
Atoms are mostly … empty. We live in almost empty space

Example: tennis ball and a grain of sand



Most of the atom's volume is occupied sparsely by electrons.

Tiny compared with the rest of the atom, the nucleus contains over 99.9% of the atom's mass.

Proton: Positive charge
Mass = 1.673×10^{-27} kg

Neutron: No charge
Mass = 1.675×10^{-27} kg

Electron: Negative charge
Mass = 9.109×10^{-31} kg

The charges of the electron and proton are equal in magnitude.

Net electric charge for a system of n particles

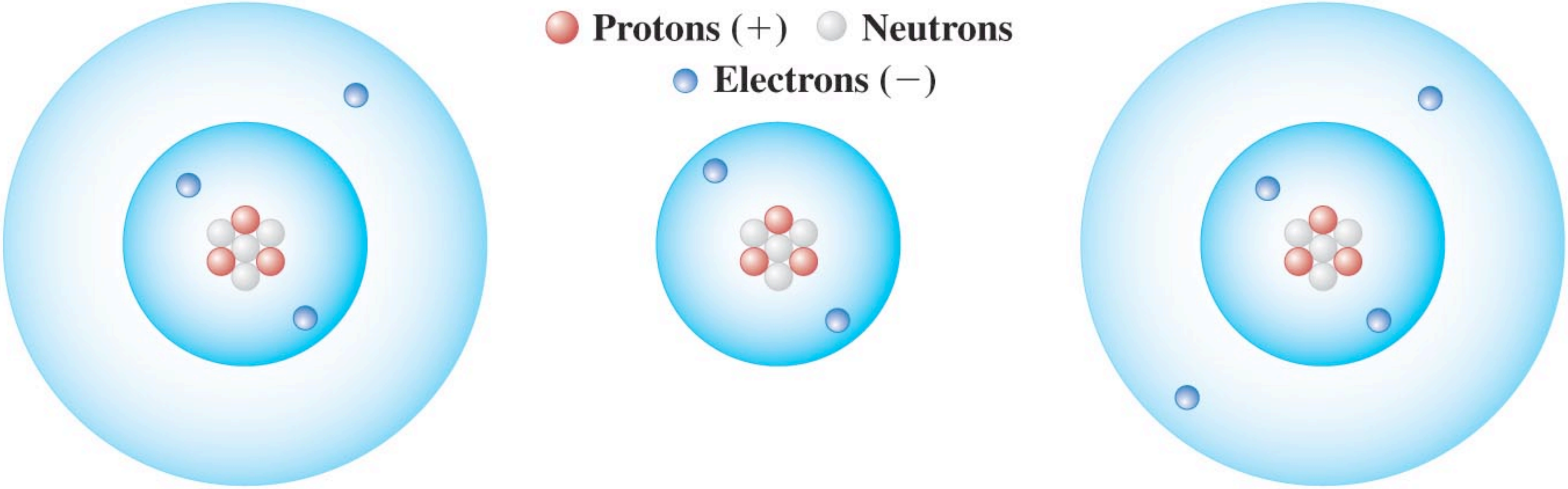
$$\boxed{q_{net} = q_1 + q_2 + q_3 + \ldots q_n}$$

The total (net) electric charge of an isolated system is conserved. The only way to change it is to add or remove charged particles.

The total electric charge of the universe is constant.

- ✓ the net electric charge of atoms and molecules is zero (equal amounts of electrons and protons)
- ✓ removing an electron from a neutral atom creates a positive ion
- ✓ negative ions?

Example:



(a) Neutral lithium atom (Li):

3 protons (3+)
4 neutrons
3 electrons (3−)

Electrons equal protons:
Zero net charge

(b) Positive lithium ion (Li^+):

3 protons (3+)
4 neutrons
2 electrons (2−)

Fewer electrons than protons:
Positive net charge

(c) Negative lithium ion (Li^-):

3 protons (3+)
4 neutrons
4 electrons (4−)

More electrons than protons:
Negative net charge

PERIODIC TABLE

Atomic Properties of the Elements

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Physics Laboratory
physics.nist.gov

Standard Reference Data Group
www.nist.gov/srd

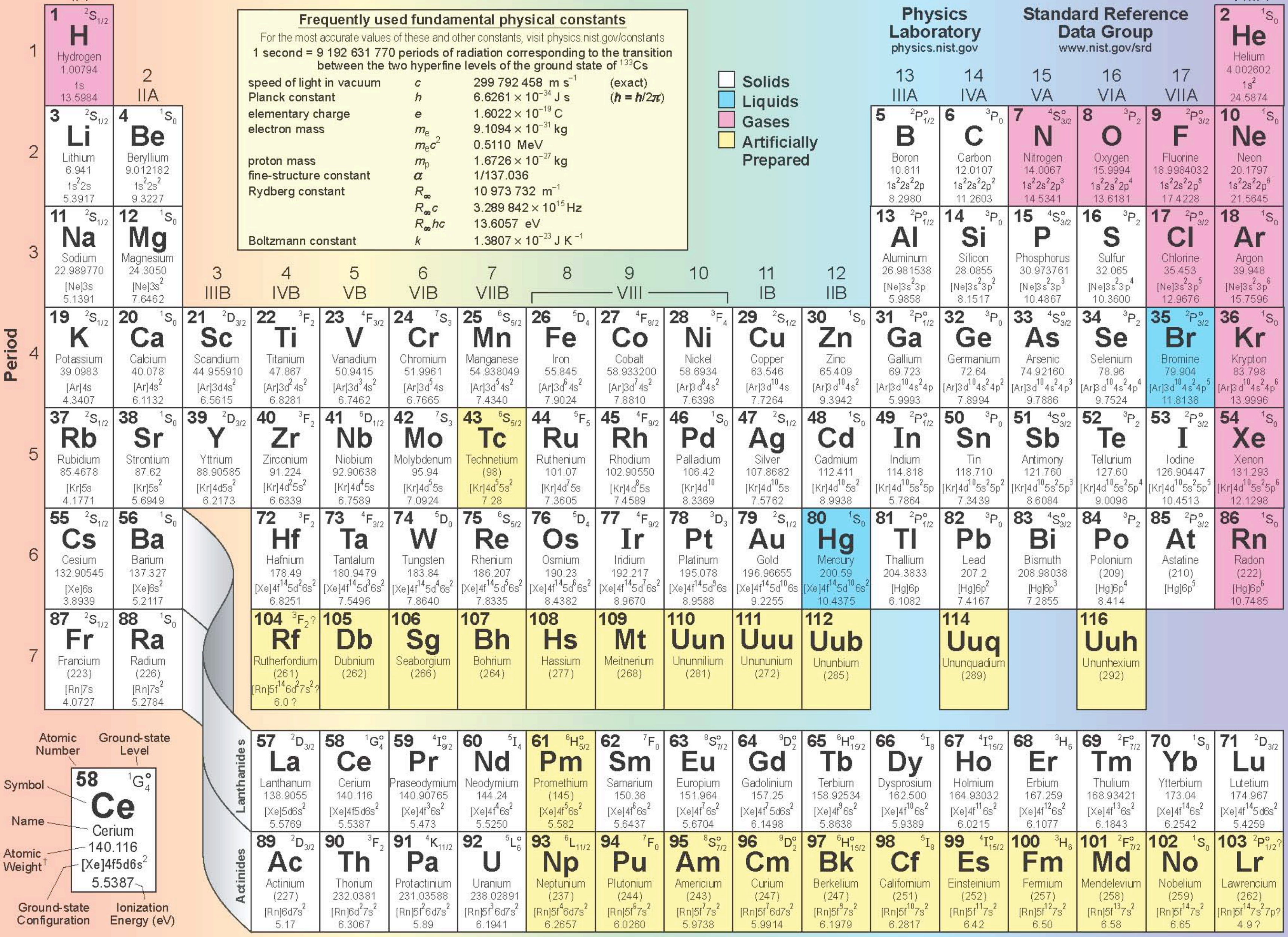
Frequently used fundamental physical constants

For the most accurate values of these and other constants, visit physics.nist.gov/constants

1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs

speed of light in vacuum	c	299 792 458 m s^{-1}	(exact)
Planck constant	h	6.6261×10^{-34} J s	($\hbar = h/2\pi$)
elementary charge	e	1.6022×10^{-19} C	
electron mass	m_e	9.1094×10^{-31} kg	
	$m_e c^2$	0.5110 MeV	
proton mass	m_p	1.6726×10^{-27} kg	
fine-structure constant	α	1/137.036	
Rydberg constant	R_∞	10 973 732 m^{-1}	
	$R_\infty c$	$3.289\,842 \times 10^{15}$ Hz	
	$R_\infty hc$	13.6057 eV	
Boltzmann constant	k	1.3807×10^{-23} J K^{-1}	

☐ Solids
🟦 Liquids
🟪 Gases
🟨 Artificially Prepared



Period	Group 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9 VIII	10 VIII	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 $^2S_{1/2}$ **H** Hydrogen 1.00794 $1s$ 13.5984																	2 $^1S_0$ **He** Helium 4.002602 $1s^2$ 24.5874
2	3 $^2S_{1/2}$ **Li** Lithium 6.941 $1s^2 2s$ 5.3917	4 $^1S_0$ **Be** Beryllium 9.012182 $1s^2 2s^2$ 9.3227											5 $^2P^\circ_{1/2}$ **B** Boron 10.811 $1s^2 2s^2 2p$ 8.2980	6 $^3P_0$ **C** Carbon 12.0107 $1s^2 2s^2 2p^2$ 11.2603	7 $^4S^\circ_{3/2}$ **N** Nitrogen 14.0067 $1s^2 2s^2 2p^3$ 14.5341	8 $^3P_2$ **O** Oxygen 15.9994 $1s^2 2s^2 2p^4$ 13.6181	9 $^2P^\circ_{3/2}$ **F** Fluorine 18.9984032 $1s^2 2s^2 2p^5$ 17.4228	10 $^1S_0$ **Ne** Neon 20.1797 $1s^2 2s^2 2p^6$ 21.5645
3	11 $^2S_{1/2}$ **Na** Sodium 22.989770 $[Ne]3s$ 5.1391	12 $^1S_0$ **Mg** Magnesium 24.3050 $[Ne]3s^2$ 7.6462											13 $^2P^\circ_{1/2}$ **Al** Aluminum 26.981538 $[Ne]3s^2 3p$ 5.9858	14 $^3P_0$ **Si** Silicon 28.0855 $[Ne]3s^2 3p^2$ 8.1517	15 $^4S^\circ_{3/2}$ **P** Phosphorus 30.973761 $[Ne]3s^2 3p^3$ 10.4867	16 $^3P_2$ **S** Sulfur 32.065 $[Ne]3s^2 3p^4$ 10.3600	17 $^2P^\circ_{3/2}$ **Cl** Chlorine 35.453 $[Ne]3s^2 3p^5$ 12.9676	18 $^1S_0$ **Ar** Argon 39.948 $[Ne]3s^2 3p^6$ 15.7596
4	19 $^2S_{1/2}$ **K** Potassium 39.0983 $[Ar]4s$ 4.3407	20 $^1S_0$ **Ca** Calcium 40.078 $[Ar]4s^2$ 6.1132	21 $^2D_{3/2}$ **Sc** Scandium 44.955910 $[Ar]3d4s^2$ 6.5615	22 $^3F_2$ **Ti** Titanium 47.867 $[Ar]3d^2 4s^2$ 6.8281	23 $^4F_{3/2}$ **V** Vanadium 50.9415 $[Ar]3d^3 4s^2$ 6.7462	24 $^7S_3$ **Cr** Chromium 51.9961 $[Ar]3d^5 4s$ 6.7665	25 $^6S_{5/2}$ **Mn** Manganese 54.938049 $[Ar]3d^5 4s^2$ 7.4340	26 $^5D_4$ **Fe** Iron 55.845 $[Ar]3d^6 4s^2$ 7.9024	27 $^4F_{9/2}$ **Co** Cobalt 58.933200 $[Ar]3d^7 4s^2$ 7.8810	28 $^3F_4$ **Ni** Nickel 58.6934 $[Ar]3d^8 4s^2$ 7.6398	29 $^2S_{1/2}$ **Cu** Copper 63.546 $[Ar]3d^{10} 4s$ 7.7264	30 $^1S_0$ **Zn** Zinc 65.409 $[Ar]3d^{10} 4s^2$ 9.3942	31 $^2P^\circ_{1/2}$ **Ga** Gallium 69.723 $[Ar]3d^{10} 4s^2 4p$ 5.9993	32 $^3P_0$ **Ge** Germanium 72.64 $[Ar]3d^{10} 4s^2 4p^2$ 7.8994	33 $^4S^\circ_{3/2}$ **As** Arsenic 74.92160 $[Ar]3d^{10} 4s^2 4p^3$ 9.7886	34 $^3P_2$ **Se** Selenium 78.96 $[Ar]3d^{10} 4s^2 4p^4$ 9.7524	35 $^2P^\circ_{3/2}$ **Br** Bromine 79.904 $[Ar]3d^{10} 4s^2 4p^5$ 11.8138	36 $^1S_0$ **Kr** Krypton 83.798 $[Ar]3d^{10} 4s^2 4p^6$ 13.9996
5	37 $^2S_{1/2}$ **Rb** Rubidium 85.4678 $[Kr]5s$ 4.1771	38 $^1S_0$ **Sr** Strontium 87.62 $[Kr]5s^2$ 5.6949	39 $^2D_{3/2}$ **Y** Yttrium 88.90585 $[Kr]4d5s^2$ 6.2173	40 $^3F_2$ **Zr** Zirconium 91.224 $[Kr]4d^2 5s^2$ 6.6339	41 $^6D_{1/2}$ **Nb** Niobium 92.90638 $[Kr]4d^4 5s$ 6.7589	42 $^7S_3$ **Mo** Molybdenum 95.94 $[Kr]4d^5 5s$ 7.0924	43 $^6S_{5/2}$ **Tc** Technetium (98) $[Kr]4d^5 5s^2$ 7.28	44 $^5F_5$ **Ru** Ruthenium 101.07 $[Kr]4d^7 5s$ 7.3605	45 $^4F_{9/2}$ **Rh** Rhodium 102.90550 $[Kr]4d^8 5s$ 7.4589	46 $^1S_0$ **Pd** Palladium 106.42 $[Kr]4d^{10}$ 8.3369	47 $^2S_{1/2}$ **Ag** Silver 107.8682 $[Kr]4d^{10} 5s$ 7.5762	48 $^1S_0$ **Cd** Cadmium 112.411 $[Kr]4d^{10} 5s^2$ 8.9938	49 $^2P^\circ_{1/2}$ **In** Indium 114.818 $[Kr]4d^{10} 5s^2 5p$ 5.7864	50 $^3P_0$ **Sn** Tin 118.710 $[Kr]4d^{10} 5s^2 5p^2$ 7.3439	51 $^4S^\circ_{3/2}$ **Sb** Antimony 121.760 $[Kr]4d^{10} 5s^2 5p^3$ 8.6084	52 $^3P_2$ **Te** Tellurium 127.60 $[Kr]4d^{10} 5s^2 5p^4$ 9.0096	53 $^2P^\circ_{3/2}$ **I** Iodine 126.90447 $[Kr]4d^{10} 5s^2 5p^5$ 10.4513	54 $^1S_0$ **Xe** Xenon 131.293 $[Kr]4d^{10} 5s^2 5p^6$ 12.1298
6	55 $^2S_{1/2}$ **Cs** Cesium 132.90545 $[Xe]6s$ 3.8939	56 $^1S_0$ **Ba** Barium 137.327 $[Xe]6s^2$ 5.2117		72 $^3F_2$ **Hf** Hafnium 178.49 $[Xe]4f^{14} 5d^2 6s^2$ 6.8251	73 $^4F_{3/2}$ **Ta** Tantalum 180.9479 $[Xe]4f^{14} 5d^3 6s^2$ 7.5496	74 $^5D_0$ **W** Tungsten 183.84 $[Xe]4f^{14} 5d^4 6s^2$ 7.8640	75 $^6S_{5/2}$ **Re** Rhenium 186.207 $[Xe]4f^{14} 5d^5 6s^2$ 7.8335	76 $^5D_4$ **Os** Osmium 190.23 $[Xe]4f^{14} 5d^6 6s^2$ 8.4382	77 $^4F_{9/2}$ **Ir** Iridium 192.217 $[Xe]4f^{14} 5d^7 6s^2$ 8.9670	78 $^3D_3$ **Pt** Platinum 195.078 $[Xe]4f^{14} 5d^9 6s$ 8.9588	79 $^2S_{1/2}$ **Au** Gold 196.96655 $[Xe]4f^{14} 5d^{10} 6s$ 9.2255	80 $^1S_0$ **Hg** Mercury 200.59 $[Xe]4f^{14} 5d^{10} 6s^2$ 10.4375	81 $^2P^\circ_{1/2}$ **Tl** Thallium 204.3833 $[Hg]6p$ 6.1082	82 $^3P_0$ **Pb** Lead 207.2 $[Hg]6p^2$ 7.4167	83 $^4S^\circ_{3/2}$ **Bi** Bismuth 208.98038 $[Hg]6p^3$ 7.2855	84 $^3P_2$ **Po** Polonium (209) $[Hg]6p^4$ 8.414	85 $^2P^\circ_{3/2}$ **At** Astatine (210) $[Hg]6p^5$	86 $^1S_0$ **Rn** Radon (222) $[Hg]6p^6$ 10.7485
7	87 $^2S_{1/2}$ **Fr** Francium (223) $[Rn]7s$ 4.0727	88 $^1S_0$ **Ra** Radium (226) $[Rn]7s^2$ 5.2784		104 $^3F_2$? **Rf** Rutherfordium (261) $[Rn]5f^{14} 6d^2 7s^2$? 6.0 ?	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (266)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (277)	109 **Mt** Meitnerium (268)	110 **Uun** Ununnilium (281)	111 **Uuu** Unununium (272)	112 **Uub** Ununbium (285)		114 **Uuq** Ununquadium (289)		116 **Uuh** Ununhexium (292)		

Lanthanides	57 $^2D_{3/2}$ **La** Lanthanum 138.9055 $[Xe]5d6s^2$ 5.5769	58 $^1G^\circ_4$ **Ce** Cerium 140.116 $[Xe]4f5d6s^2$ 5.5387	59 $^4I^\circ_{9/2}$ **Pr** Praseodymium 140.90765 $[Xe]4f^3 6s^2$ 5.473	60 $^5I_4$ **Nd** Neodymium 144.24 $[Xe]4f^4 6s^2$ 5.5250	61 $^6H^\circ_{5/2}$ **Pm** Promethium (145) $[Xe]4f^5 6s^2$ 5.582	62 $^7F_0$ **Sm** Samarium 150.36 $[Xe]4f^6 6s^2$ 5.6437	63 $^8S^\circ_{7/2}$ **Eu** Europium 151.964 $[Xe]4f^7 6s^2$ 5.6704	64 $^9D^\circ_2$ **Gd** Gadolinium 157.25 $[Xe]4f^7 5d6s^2$ 6.1498	65 $^6H^\circ_{15/2}$ **Tb** Terbium 158.92534 $[Xe]4f^9 6s^2$ 5.8638	66 $^5I_8$ **Dy** Dysprosium 162.500 $[Xe]4f^{10} 6s^2$ 5.9389	67 $^4I^\circ_{15/2}$ **Ho** Holmium 164.93032 $[Xe]4f^{11} 6s^2$ 6.0215	68 $^3H_6$ **Er** Erbium 167.259 $[Xe]4f^{12} 6s^2$ 6.1077	69 $^2F^\circ_{7/2}$ **Tm** Thulium 168.93421 $[Xe]4f^{13} 6s^2$ 6.1843	70 $^1S_0$ **Yb** Ytterbium 173.04 $[Xe]4f^{14} 6s^2$ 6.2542	71 $^2D_{3/2}$ **Lu** Lutetium 174.967 $[Xe]4f^{14} 5d6s^2$ 5.4259
Actinides	89 $^2D_{3/2}$ **Ac** Actinium (227) $[Rn]6d7s^2$ 5.17	90 $^3F_2$ **Th** Thorium 232.0381 $[Rn]6d^2 7s^2$ 6.3067	91 $^4K_{11/2}$ **Pa** Protactinium 231.03588 $[Rn]5f^2 6d7s^2$ 5.89	92 $^5L^\circ_6$ **U** Uranium 238.02891 $[Rn]5f^3 6d7s^2$ 6.1941	93 $^6L_{11/2}$ **Np** Neptunium (237) $[Rn]5f^4 6d7s^2$ 6.2657	94 $^7F_0$ **Pu** Plutonium (244) $[Rn]5f^6 7s^2$ 6.0260	95 $^8S^\circ_{7/2}$ **Am** Americium (243) $[Rn]5f^7 7s^2$ 5.9738	96 $^9D^\circ_2$ **Cm** Curium (247) $[Rn]5f^7 6d7s^2$ 5.9914	97 $^6H^\circ_{15/2}$ **Bk** Berkelium (247) $[Rn]5f^9 7s^2$ 6.1979	98 $^5I_8$ **Cf** Californium (251) $[Rn]5f^{10} 7s^2$ 6.2817	99 $^4I^\circ_{15/2}$ **Es** Einsteinium (252) $[Rn]5f^{11} 7s^2$ 6.42	100 $^3H_6$ **Fm** Fermium (257) $[Rn]5f^{12} 7s^2$ 6.50	101 $^2F^\circ_{7/2}$ **Md** Mendelevium (258) $[Rn]5f^{13} 7s^2$ 6.58	102 $^1S_0$ **No** Nobelium (259) $[Rn]5f^{14} 7s^2$ 6.65	103 $^2P^\circ_{1/2}$? **Lr** Lawrencium (262) $[Rn]5f^{14} 7s^2 7p$? 4.9 ?

† Based upon ^{12}C. () indicates the mass number of the most stable isotope.

For a description of the data, visit physics.nist.gov/data

NIST SP 966 (September 2003)

?

To make an uncharged object to have a negative charge we must:

A) add some atoms
B) add some protons
C) add some electrons
D) add some neutrons
E) write down a negative sign

Macro objects (many atoms or molecules)

Materials – two extreme models

Insulators – a material in which charges do not move freely though the interior of the sample. Examples: Glass, wood, rubber, plastics, stone, brick, etc

Conductors – material where free charges can move through the material. Examples: Ionized gases (plasmas), metals, ionic solutions if salts in water

Semi-conductors – a material intermediate between the two extreme models – GaAs, Ge, Si, are the classic examples.

Macro objects can be charged by charge transfer or charge separation

- ✓ Charge transfer happens when electric charges (usually electrons) transfer from one object to another
- ✓ Charge separation occurs when two material are rubbed together or when objects collide

Charge is quantized

Experiments show that any positive or negative charge q that can be detected can be written as

$$\boxed{\begin{array}{l} q = n \cdot e, \quad n = \pm 1, \pm 2, \pm 3, \ldots \\ e = 1.60 \times 10^{-19} C \end{array}}$$

where e is the **elementary charge**.

from a simple to complex

Universe

human beings

cells

condensed matter, gases

molecules

atoms

electrons, protons, neutrons

fundamental particles: electrons, quarks, …

Note: *ALL* electrons are identical, as well as protons, neutrons …

Part 3

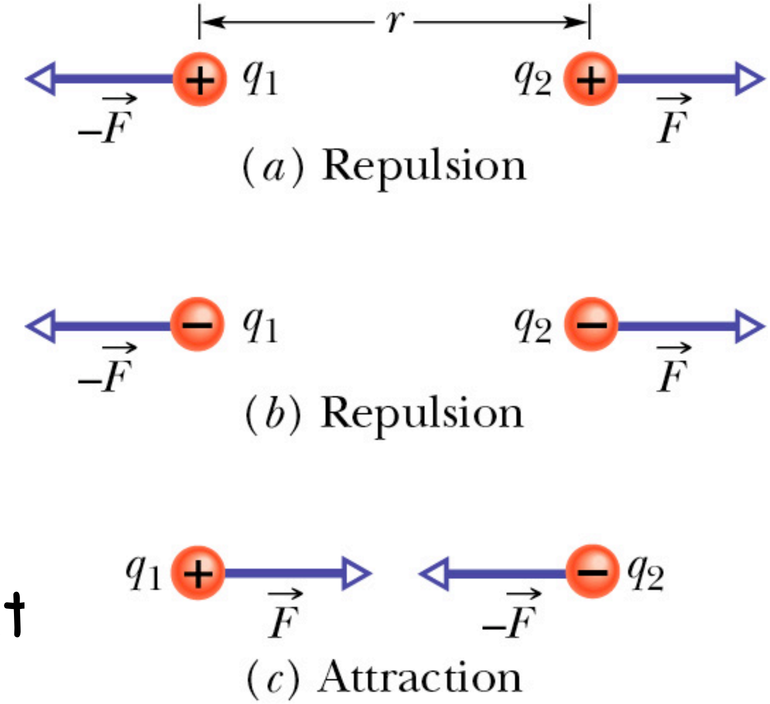
A force between charges

Coulomb's Law

The **electrostatic force** between two charges q_1 and q_2 separated by a distance r has the magnitude

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

$$\boxed{\mathrm{k} = \frac{1}{4\pi\varepsilon_0} = 8.99\times10^9\ \mathrm{N\cdot m^2/C^2}}$$

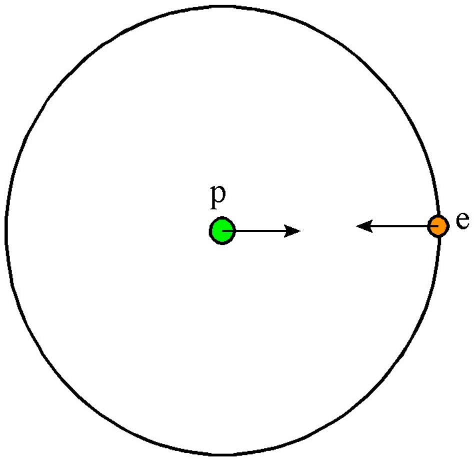


k is the electromagnetic constant
ε_0 is the permittivity constant

Where is the 3rd Newton's law?

Comparing the gravitational and electrostatic forces

Let's calculate the ratio of the electrical to the gravitational force inside a hydrogen atoms.



$$F_g = \frac{GM_pM_e}{R^2}, F_e = \frac{k_eq_pq_e}{r^2}$$

$$\frac{F_e}{F_g} = \frac{\frac{k_eq_pq_e}{\cancel{r^2}}}{\frac{GM_pM_e}{\cancel{r^2}}} = \frac{k_eq_pq_e}{GM_pM_e}$$

$$\frac{F_e}{F_g} = \frac{(9\times10^9)(1.6\times10^{-19})^2}{(6.67\times10^{-11})(1.67\times10^{-27})(9.11\times10^{-31})}$$

$$= 2.27\times10^{39}$$

So we can forget gravity as compared to electrostatic forces – at least on the atomic scale

A contradiction to a simple observation?

If $F_e/F_{Gl} = 2.27\times10^{39}$ then, why the gravity force plays any observable role?

- ✓ The force of gravity plays essentially NO role in atomic and molecular systems
- ✓ However macroscopic objects are neutral or almost neutral (the net electric charge is close to zero) Therefore the force of gravity play strong role for macroscopic objects

Coulomb's law and the principle of superposition

The principle of superposition: the net effect is the sum of the individual effects

For n interacting particles the net force on particle 1 can be written as

$$\boxed{\vec{F}_{1,net} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \ldots \vec{F}_{1n}}$$

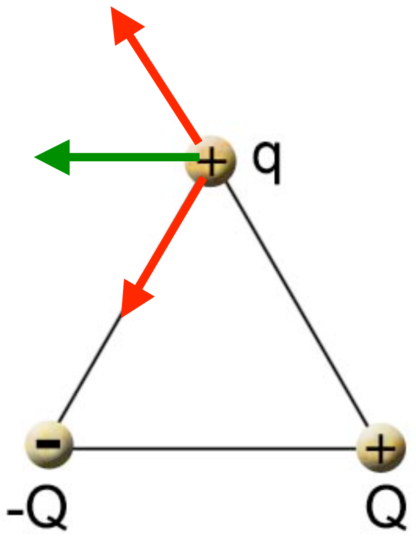
being practical – see chapter 3 "Vectors in Physics" (adding vectors using components)

Net Force and the superposition principle

?

Charges Q, -Q, and q are placed at the vertices of an equilateral triangle as shown. The total force exerted on the charge q is:

A) toward charge Q
B) toward charge -Q
C) away from charge Q
D) parallel to the line joining Q and -Q



Always draw a free body diagram!

Net Force

?

Two point charges are arranged as shown, where Q_1 = -2C, Q_2 = 1C. In which region could a third charge +1 C be placed so that the net electrostatic force on it is zero?

A) I only
B) I and II only
C) III only
D) I and III only
E) II only

What if the third charge is q=-1C?

What if the particles have charges Q and -Q?

What if the particles have charges Q and Q?

?

Net Force 2

Four identical point charges are placed at the corners of a square. A fifth point charge placed at the center of the square experiences zero net force.
Is this a stable equilibrium for the fifth charge?

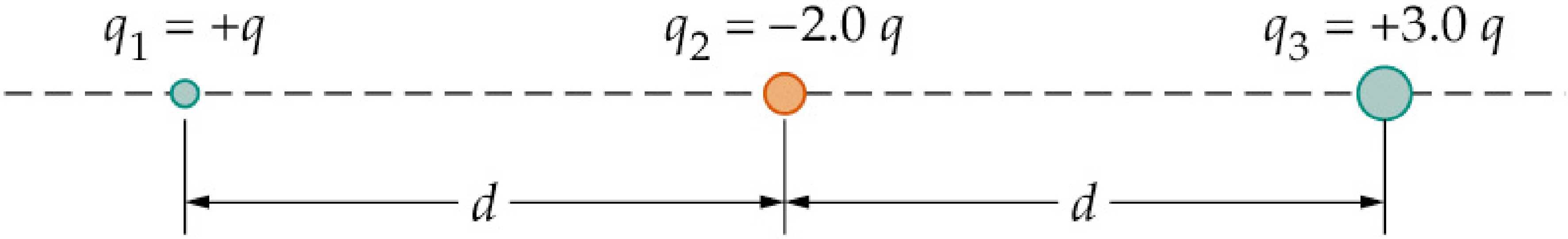
problem

Example: 3 electric charges in a line

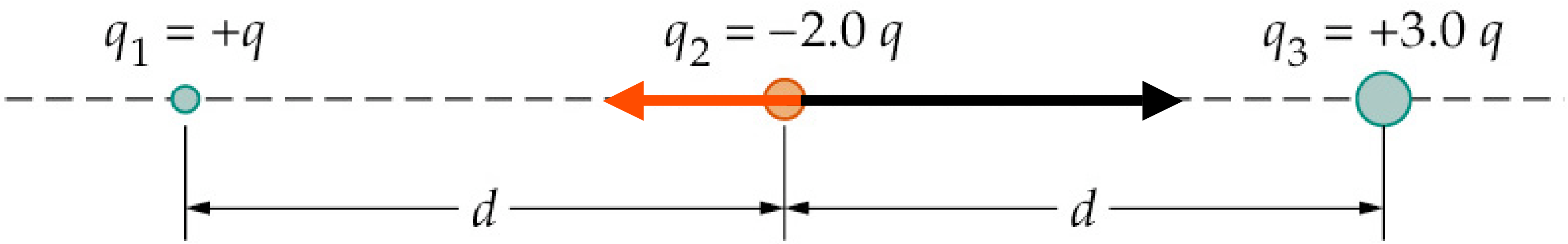
Given that q = +12 mC and d = 16 cm,

(a) find the direction and magnitude of the net electrostatic force exerted on the point charge q_2 in Figure below?

(b) How would your answers to part (a) change if the distance d were tripled?



problem



$$F_{blue} = \frac{1}{4\pi\varepsilon_0}\frac{3.0q \times 2.0q}{d^2} = 9 \times 10^9 \times \frac{3.0q \times 2.0q}{d^2}$$

$$F_{red} = \frac{1}{4\pi\varepsilon_0}\frac{1.0q \times 2.0q}{d^2} = 9 \times 10^9 \times \frac{1.0q \times 2.0q}{d^2}$$

$$F_{\text{resultant}} = 9 \times 10^9 \times \left[\frac{3.0q \times 2.0q}{d^2} - \frac{1.0q \times 2.0q}{d^2}\right] \text{ to the right}$$

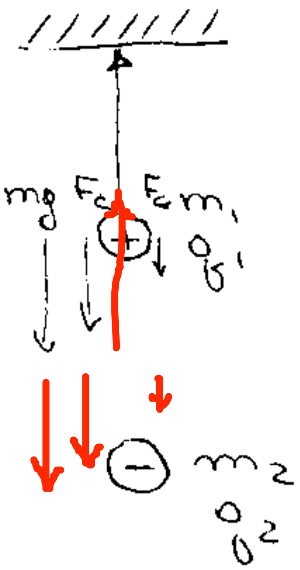
problem

Problem 1. (10 points)

A small object of mass 0.025 kg and charge 1.9 μC hangs from the ceiling by a thread. A second small object of mass 0.50 kg and charge -4.2 μC, is placed 52 cm vertically below the first charge.

(a) Find the tension in the thread

(b) Find the ratio of the electrical to the gravitational force between the objects.



a) $T = m_1 g + k\frac{q_1 q_2}{r^2} + \cancel{G\frac{m_1 m_2}{r^2}} = 0.51\ N$

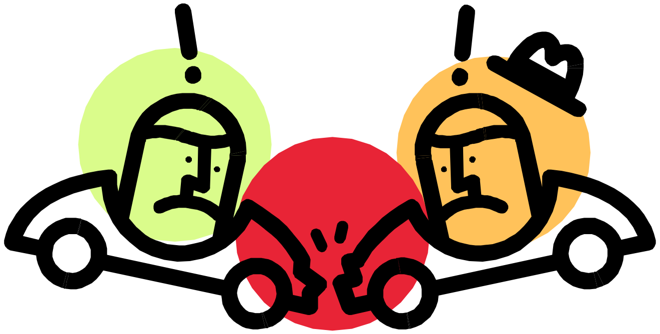
too small

B) $R = \frac{F_C}{F_G} = \frac{k\frac{q_1 q_2}{r^2}}{G\frac{m_1 m_2}{r^2}} = \frac{k q_1 q_2}{G m_1 m_2} = 8.6\cdot 10^{10}$

problem

A tale of two particles

An electron and a proton are released from rest in space, far from any other object. The particles move toward each other, due to their mutual attraction. When they meet, is the kinetic energy of the electron greater than, less than, or the same as the kinetic energy of the proton?
Explain.



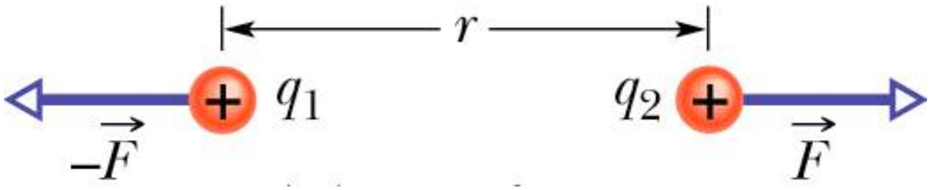
Part 4

Electric Field

A couple of "simple" questions

The Coulomb law

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



How does q_1 "know" of the presence of q_2?

Since the charges do not touch, how can q_1 exert a force on q_2?

Action on a distance!

Other examples?

Electric Fields or Action on a Distance

We can say that q_1 sets up an **electric field** in the space surrounding it.

1. At any given point P in that space the field has both magnitude and direction.
2. The magnitude depends on the magnitude of q_1 and the distance between P and q_1.
3. The direction depends on the direction from q_1 to P and the electrical sign of q_1.
4. Thus when we place q_2 at P, q_1 interacts with q_2 through the electric field at P.

The electric field is a vector field

The electric field consists of a distribution of vectors, one for each point in the region around a charged object. A way to define the electric field at some point P

1. Place a positive charge q_0, called a test charge, at the point P
2. Measure the electrostatic force $\vec{F}$ that acts on the test charge
3. Define the electric field at the point P due to the charged object as

$$\boxed{\vec{E} = \frac{\vec{F}}{q_0}}$$

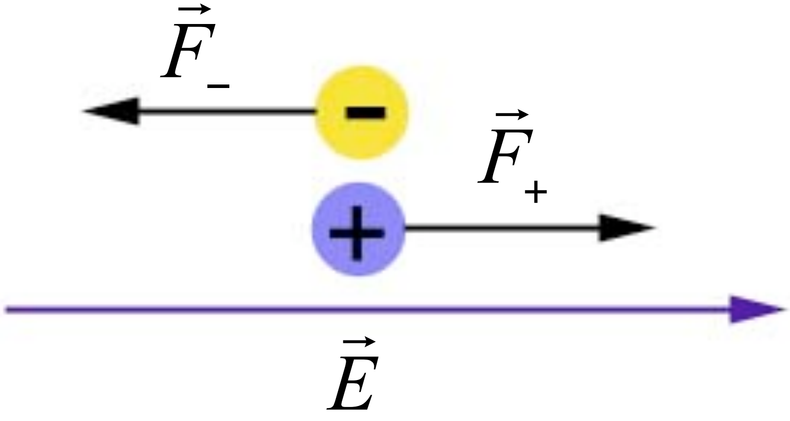
The SI unit for the electric field is the newton per coulomb (N/C)

A particle in an electric field

1. If we know the electric field vector at a given point, the force that a charge q experiences at that point is

$$\boxed{\vec{F} = q\vec{E}}$$

2. The direction of the force:
   positive particles – in the direction of the field
   negative particles – in the opposite direction of the field



The electric field due to a point electric charge

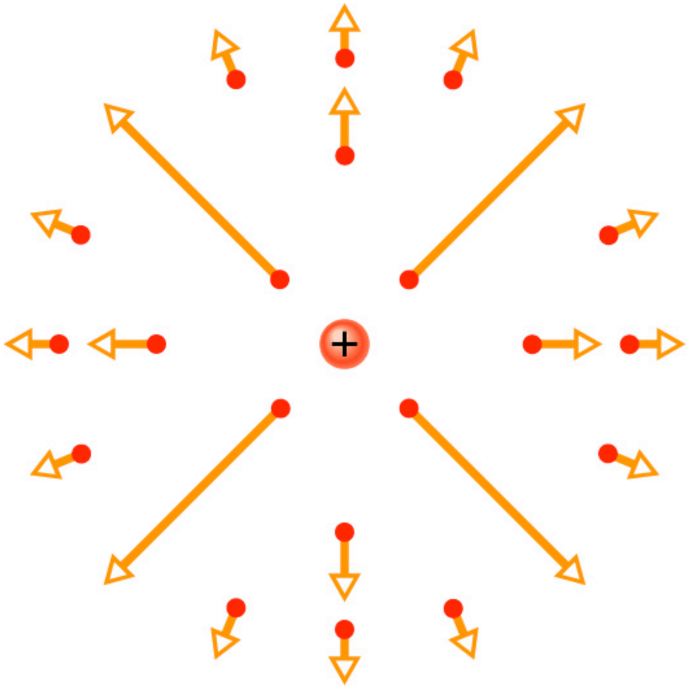
From Coulomb's law, the magnitude of the electrostatic force acting on q_0 is

$$F = k\frac{|q||q_0|}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{|q||q_0|}{r^2}$$

The direction of the force is directly away from the point charge if q is positive, and directly toward the point charge is q is negative. Then the magnitude of the electric field from a point charge is

$$\boxed{E = k\frac{|q|}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}}$$

Example



Electric field around a positive electric charge

The electric field due to more than one point electric charge

Using the superposition principle we can find the net force

$$\vec{F}_{0,net} = \vec{F}_{01} + \vec{F}_{02} + \vec{F}_{03} + \ldots \vec{F}_{0n}$$

Therefore the net electric field at the position of the test charge is

$$\vec{E} = \frac{\vec{F}_{0,net}}{q_0} = \frac{\vec{F}_{01}}{q_0} + \frac{\vec{F}_{02}}{q_0} + \frac{\vec{F}_{03}}{q_0} + \ldots \frac{\vec{F}_{0n}}{q_0}$$

$$\boxed{\vec{E} = \vec{E}_{01} + \vec{E}_{02} + \vec{E}_{03} + \ldots \vec{E}_{0n}}$$

?

Conceptual question

A proton moves in a region of constant electric field.

Does it follow that the proton's velocity is parallel to the electric field?

Does it follow that the proton's acceleration is parallel to the electric field?

Conceptual question

The force experienced by charge 1 at point A is different in direction and magnitude from the force experienced by charge 2 at point B.

Can we conclude that the electric fields at point A and point B are different?

Tools (equations) to describe motion of electrons

atoms molecules	quantum mechanics	Schrodinger equation Dirac equation
gases, plasma, …	classical mechanics	Second Newton's law

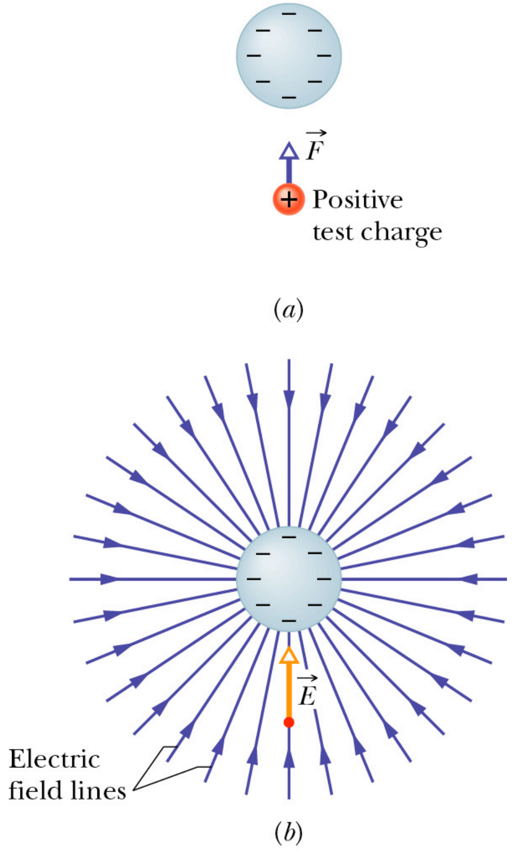
$$\vec{F} = q\vec{E} = m\vec{a}$$

Part 5

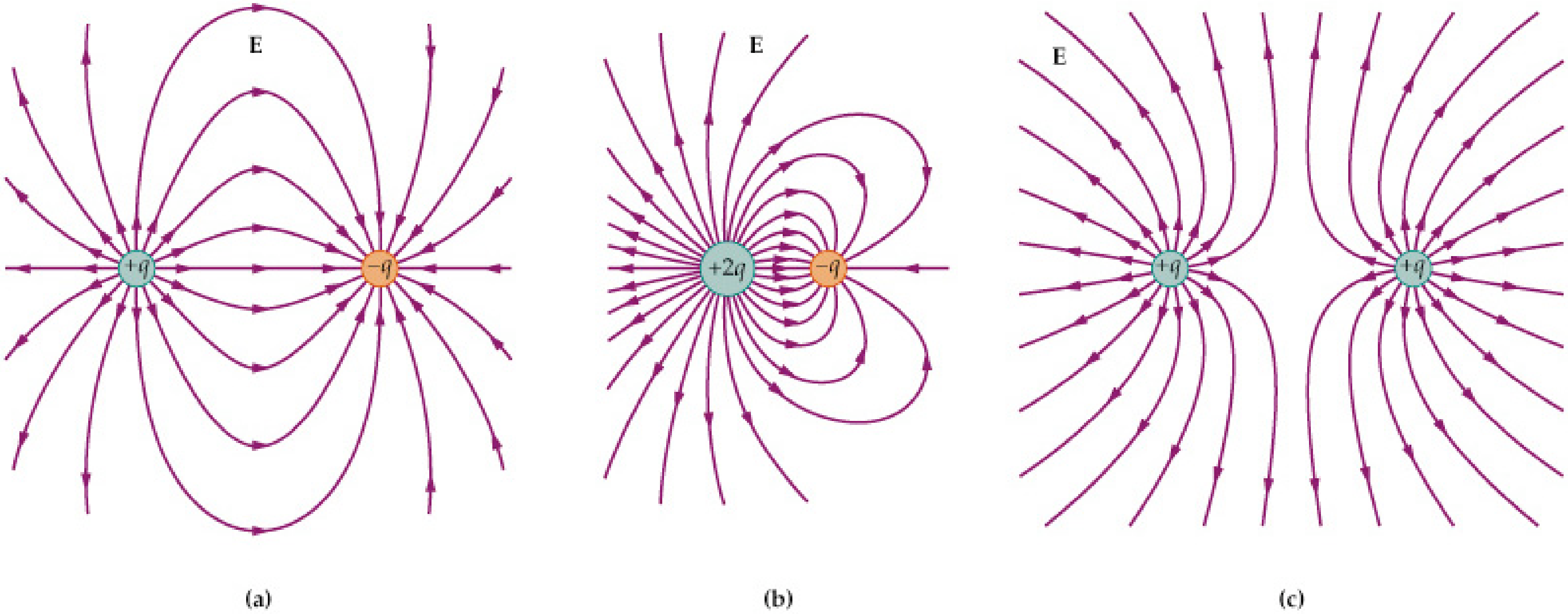
Electric Field Lines

Electric field **lines** provide a nice way to visualize patterns in electric fields

1. At any point, the direction of a straight field line gives the direction of the electric field at that point
2. Electric fields extend away from positive charge and toward negative charge
3. No field lines cross.
4. The field lines are drawn so that the number of lines per unit area is proportional to the *magnitude* of the electric field.



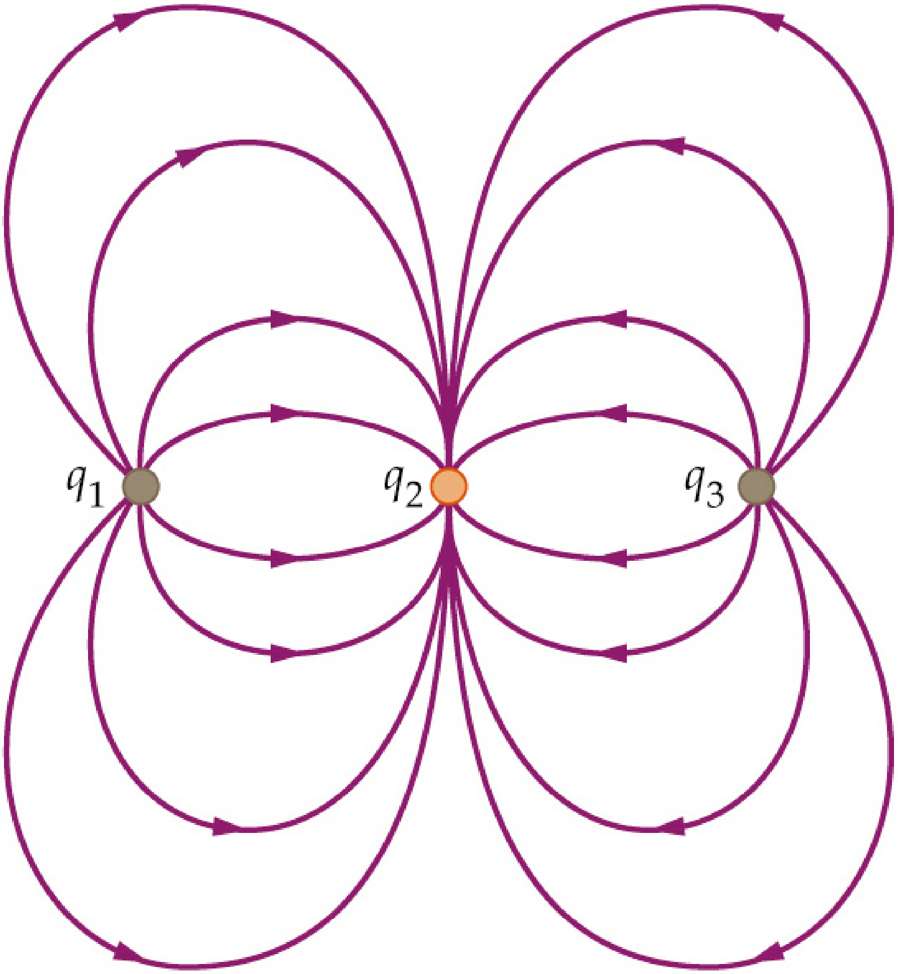
Examples



(a) (b) (c)

Note that twice as many field lines originate from the +2*q* charge than the +*q* or −*q* charges.

Problem



The electric field lines surrounding three charges are shown in the Figure. The center charge is q_2 = -10.0 mC.

(a) What are the signs of q_1 and q_3?

(b) Find q_1.

(c) Find q_3.

Part 6

Flux of an Electric Field

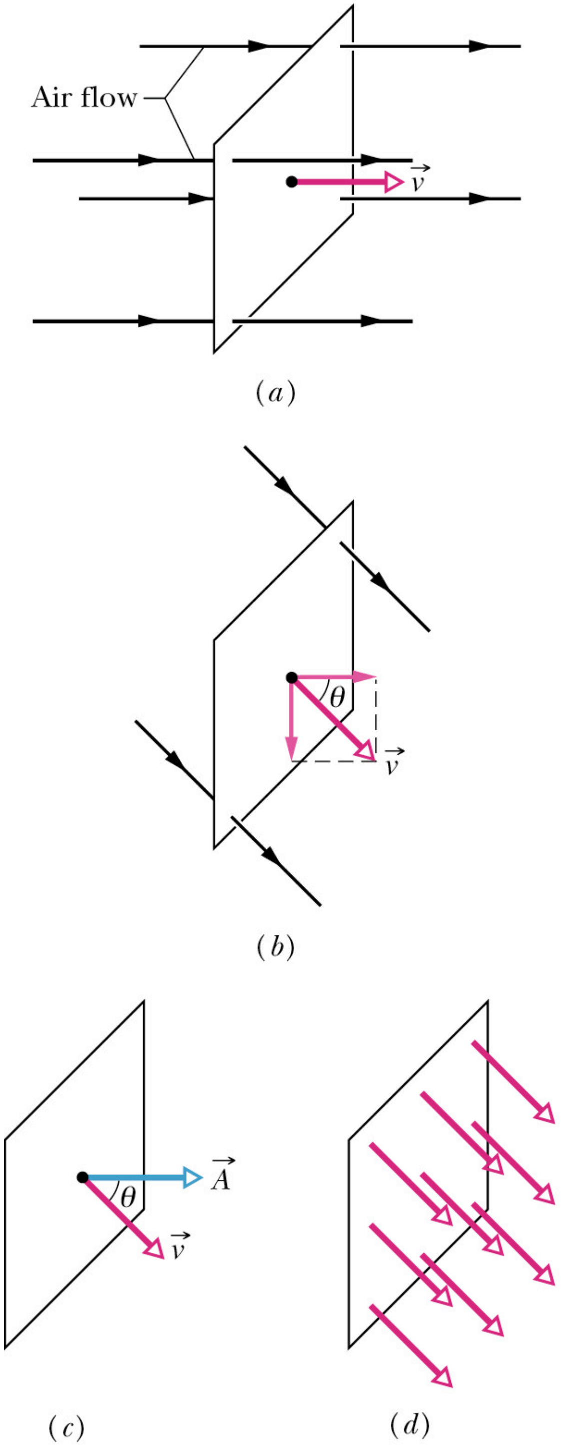
Flux

Example: a wide air stream of uniform velocity at a small square loop of area *A*.

Let Φ represents the *volume flow rate* (volume per unit time) at which air flows through the loop.

The rate depends on the angle between the velocity and the plane of the loop.

$$\boxed{\Phi = (v\cos\theta)A = vA\cos\theta}$$



Flux of an Electric Field

$$\boxed{\Phi = EA\cos\theta}$$

θ is the angle between the electric field and the line perpendicular to the surface.

SI units: $N{\cdot}m^2/C$

For a non-uniform fields we have to integrate over a surface

The electric flux through a surface is proportional to the net number of electric field lines passing through that surface.

Gauss' Law

Gauss' law relates the net flux Φ of an electric field through a closed surface to the net charge q_{enc} that is enclosed by that surface

$$\boxed{\varepsilon_0 \Phi = q_{enc}}$$

Gauss' law and Coulomb's law

Demonstration for a point charge

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} \qquad \Phi = EA = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}4\pi r^2 = \frac{q}{\varepsilon_0}$$

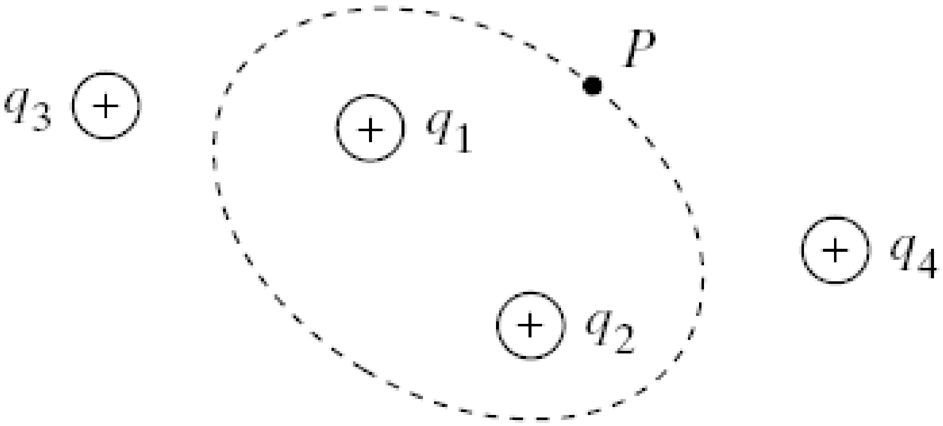
$$A = 4\pi r^2$$

Example

In the following figure, the dashed line denotes a Gaussian surface enclosing part of a distribution of four positive charges.

(a) Which charges contribute to the electric field at P?

(b) Is the value of the flux through the surface, calculated using only the electric field due to q1 and q2, greater than, equal to, or less than that obtained using the field due to all four charges?

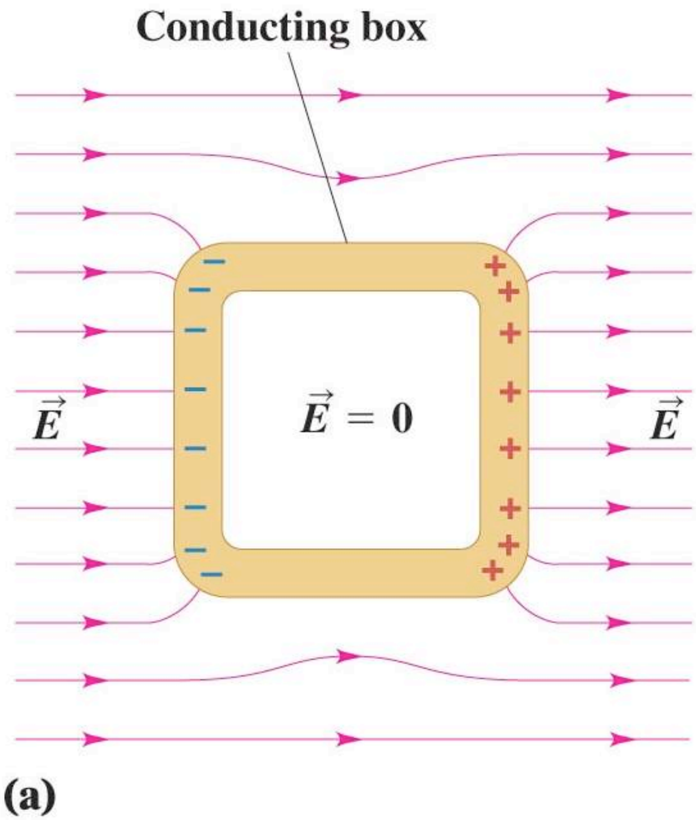


A practical conclusion from the Gauss's Law – Faraday's cage

During a thunderstorm – stay in your car!!!

The field induces charges on the left and right sides of the conducting box.

The total electric field inside the box is zero; the presence of the box distorts the field in adjacent regions.



Epilogue

Interactive Computer Simulation

A very good collection of interactive simulations to learn physics from the Physics Education Technology project at the University of Colorado http://www.colorado.edu/physics/phet/