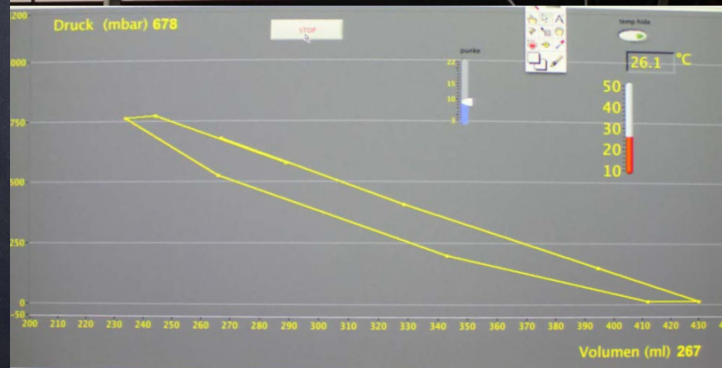
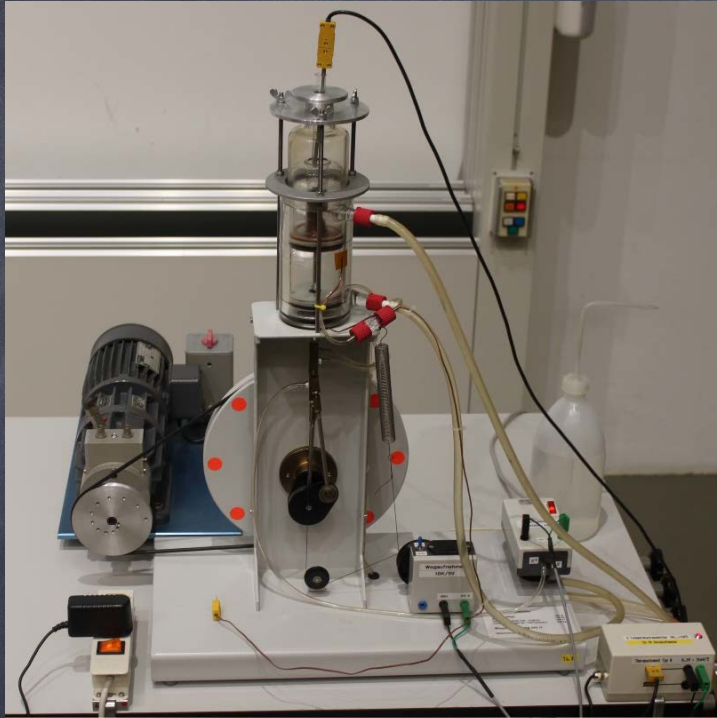


PHY 117 HS2023

Week 8, Lecture 1

Nov. 7th, 2023

Prof. Ben Kilminster



Previously, we found that the best possible efficiency for a perfect reversible engine is related to the temp. difference:

$$\epsilon_c = 1 - \frac{T_c}{T_H} \Rightarrow \frac{T_c}{T_H} = \frac{|Q_c|}{|Q_H|}$$

Power plant generating electricity from fossil fuels: $\epsilon_c \sim 50\%$

Actual efficiency is 40%

$$\epsilon_{SL} = \frac{\epsilon}{\epsilon_c} = \frac{40\%}{50\%} = 80\%$$

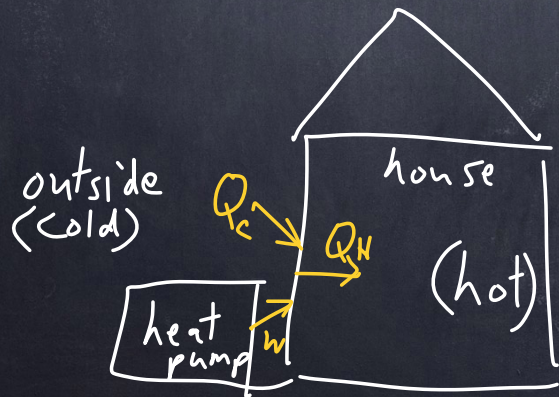
Electrical house heater efficiency =

$$\text{power plant efficiency} * \text{transmission efficiency} * \text{electrical heater efficiency}$$

$$= (67\%) * (95\%) * (100\%) = 64\%$$

But, if the goal is to heat a house, we can do much better.

A heat pump is a refrigerator that removes Q_c of heat from a cold reservoir and puts Q_H of heat into a hot reservoir, using W amount of work.

$$|Q_c| + W = |Q_H|$$


What is the efficiency of a heat pump?

$$\text{C.O.P.} = \frac{|Q_c|}{W} = \frac{Q_c}{|Q_H| - |Q_c|}$$

divide the top + bottom by $|Q_H|$ \Rightarrow C.O.P. = $\frac{|Q_c|}{|Q_H|} \frac{|Q_H|}{|Q_H| - |Q_c|}$

Using our Carnot conditions, we can replace

$$\text{C.O.P.} = \frac{\frac{T_c}{T_H}}{1 - \frac{T_c}{T_H}} = \frac{T_c}{T_H - T_c} = \boxed{\frac{T_c}{\Delta T} = \text{COP}_{\text{max}}}$$

$Q_c \rightarrow T_c$
 $Q_H \rightarrow T_H$
 \rightarrow the smaller the ΔT the better the performance.

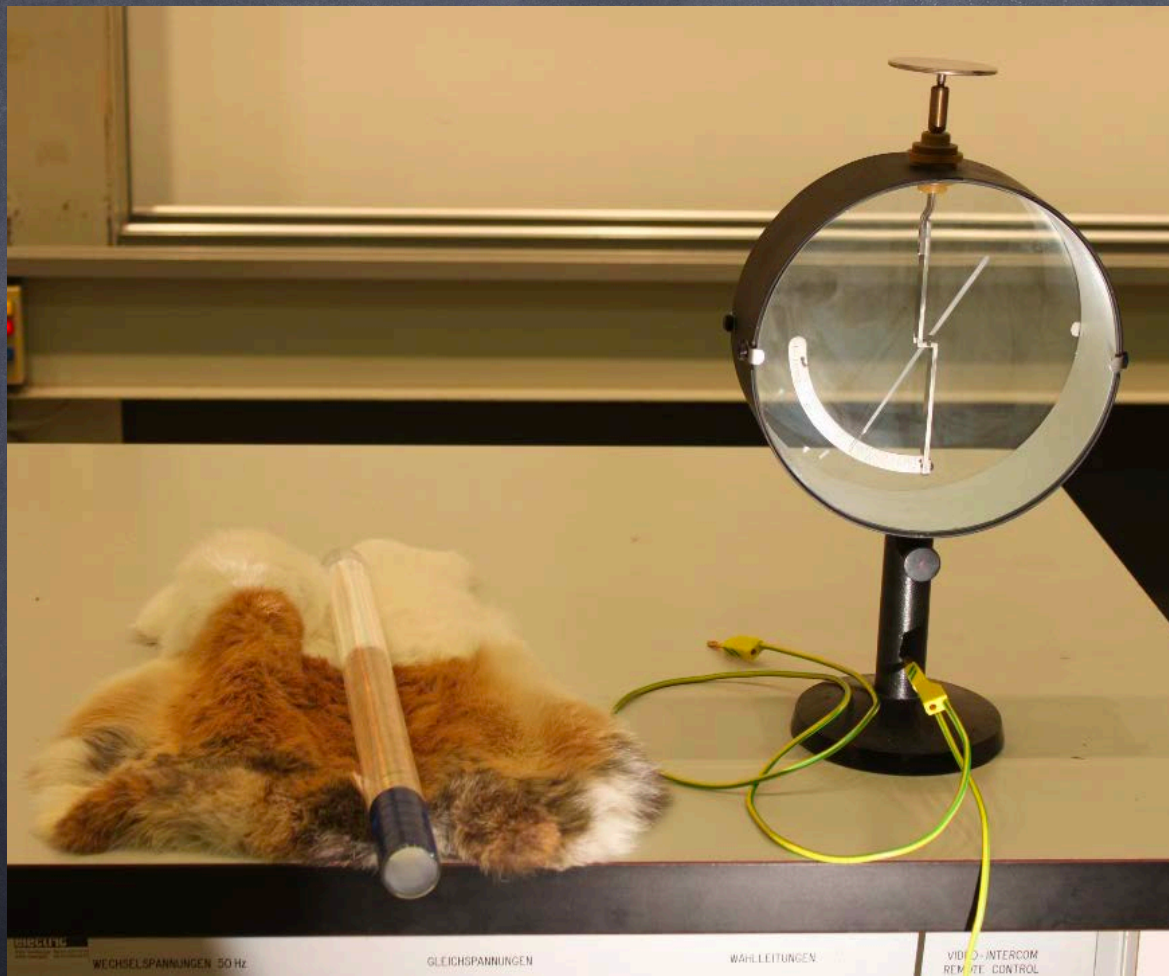
As an efficiency, $\varepsilon = \frac{Q_H}{W} = \frac{W(1 + \text{C.O.P.})}{W}$

Typical C.O.P. ~ 3.5 , then $\varepsilon = 1 + 3.5 = 4.5 \Rightarrow 450\%$

e.g.) with 100 watts of power \rightarrow 450 W of heat generated.

Compare 450% to 64% for electrical heater.

\Rightarrow Heat pumps rule!



BRUNNEN

WECHSELSPANNUNGEN 50 Hz

GLEICHSPANNUNGEN

WÄRMELEITUNGEN

VIDEO-INTERCOM
REMOTE CONTROL

Electrostatics:

Observations: 3 groups of charged objects:

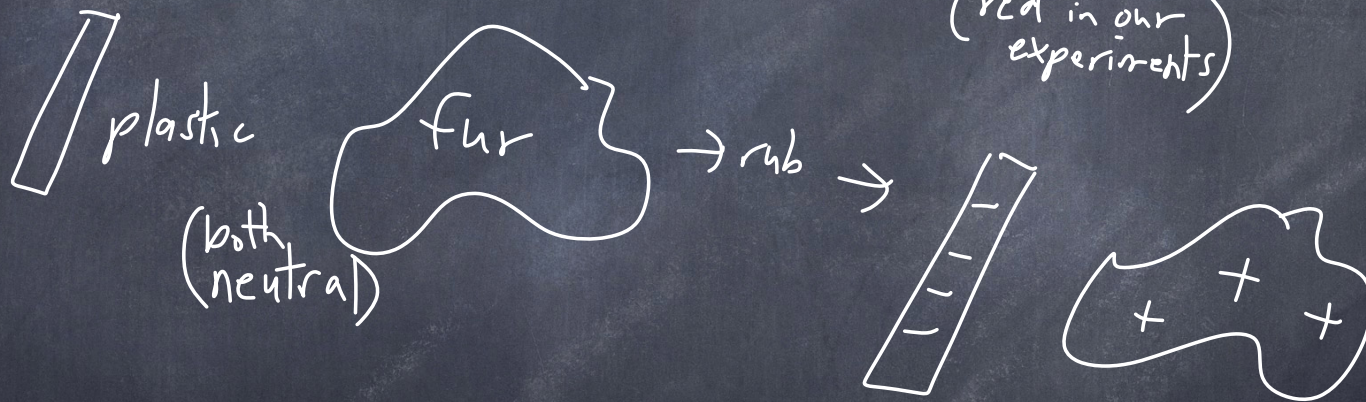
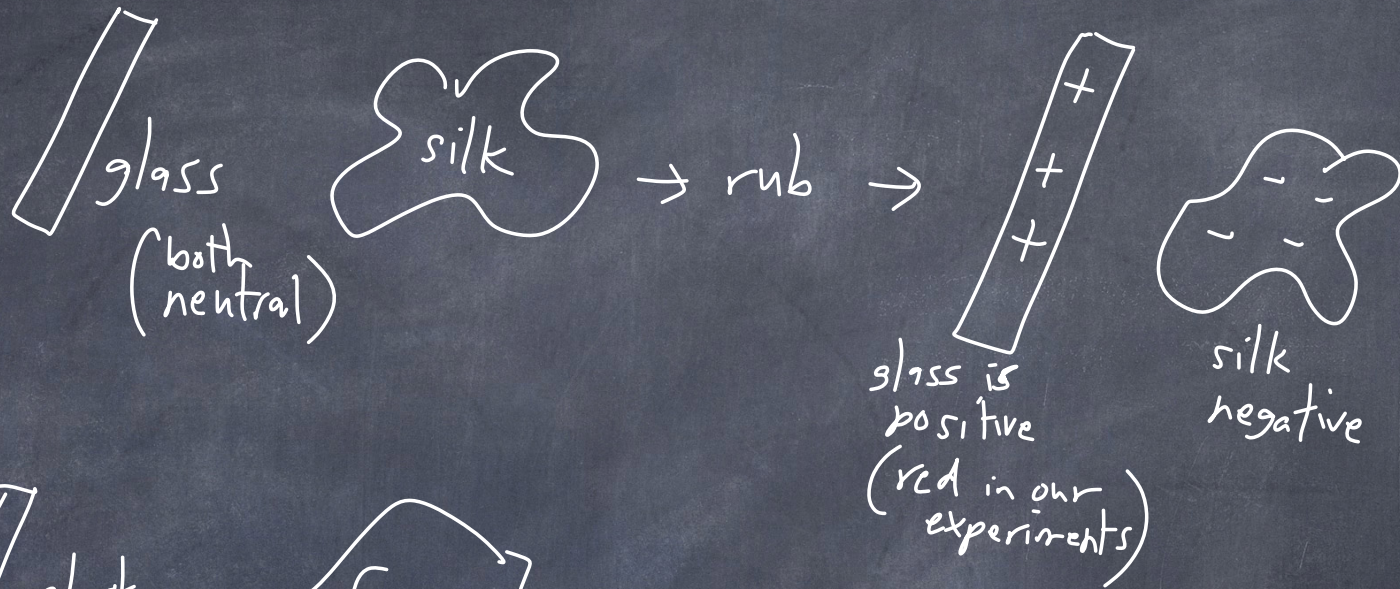
- 1) pairs attract
- 2) pairs repel
- 3) pairs that do nothing

Ideas: 1) something called charge exists

2) we can move charge

3) attraction or repulsion between charged objects.

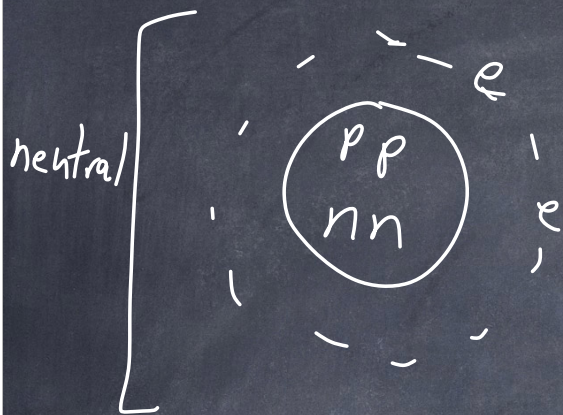
Benjamin
Franklin
convention



Now, we know that:

- negative charges are electrons (the moving charges in solids)
- charge $\equiv Q$; +, -, 0

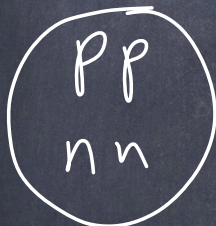
Matter consists of atoms



	<u>Q (charge)</u>
proton = p	+e
neutron = n	0
electron = e	-e

e: fundamental unit of charge

charge
 $+Ze$



ion: charged atom

we have observed that charge is quantized.

$$Q = \pm Ne$$

N: integer $\dots, -3, -2, -1, 0, 1, 2, 3, \dots$

The unit of charge is the Coulomb, [C]

A single electron has a charge of $-e$

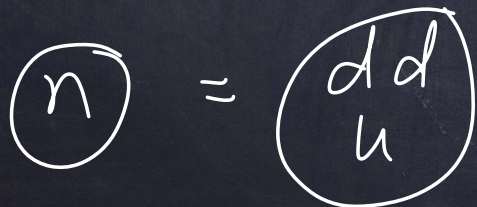
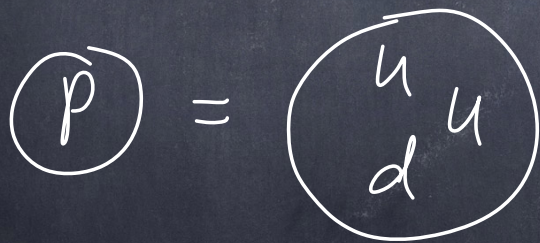
$$e = 1.6 \times 10^{-19} \text{ C}$$

Rubbing materials together (static electricity)
typically produces charges $\sim 10^{-8} \text{ C} = 0.01 \mu\text{C}$

$$\# \text{ electrons} = 10^{-8} \text{ C} \cdot \frac{1e}{1.6 \times 10^{-19} \text{ C}} = 6 \times 10^{\text{electrons}}$$

Note: It is unknown why a proton has the opposite charge as an electron. A proton is actually a composite particle, and has a mass 2000 times greater than an electron.
(Electron is a fundamental particle)

Experiments have shown that a proton is really made of 3 quarks, each with a fractional charge.



$$u: \text{ up quark } Q(u) = +\frac{2}{3}e$$

$$d: \text{ down quark } Q(d) = -\frac{1}{3}e$$

$$Q(p) = +1e$$

$$Q(n) = -\frac{1}{3}e + -\frac{1}{3}e + \frac{2}{3}e = 0$$

Quarks are observed only as combinations with integer electric charge. We can study quarks individually in a particle collider, like at CERN LHC

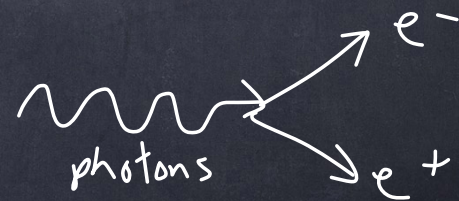
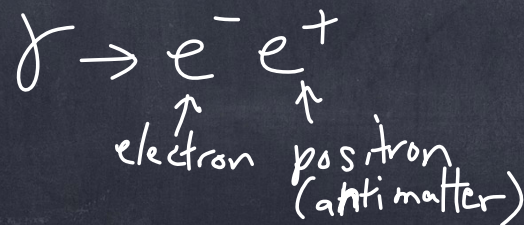
Charge conservation is a law of Nature.

(like energy + momentum conservation)

Electric charges move, but don't disappear.

Caveat: In particle physics, you can destroy + create particles, but conservation laws still apply:

photon: γ



$$Q(\gamma) = 0 \rightarrow (-1) + (+1) = 0$$

Conductors - in some materials, electrons are free to move around.

insulators - materials where electrons are bound to atoms tightly, & do not move freely.

For instance, copper is a good conductor.

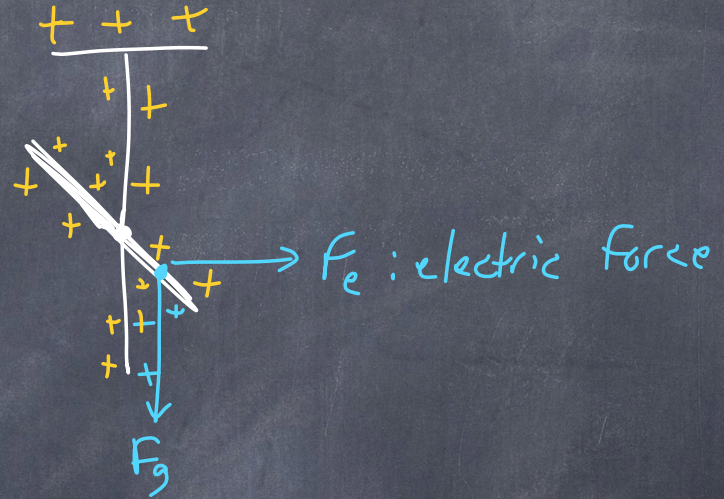
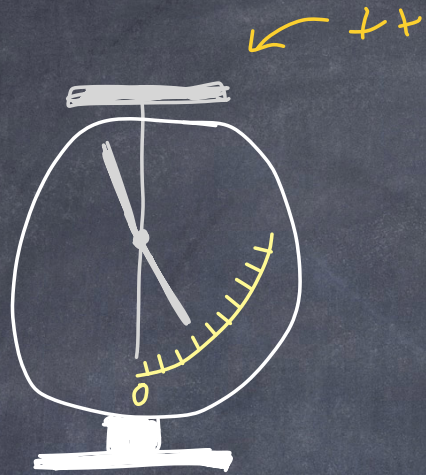
When you combine a large number of copper atoms together, the binding energy of the electrons changes. One or more electrons per atom becomes free to move around the material.

Normally neutral, but can have + or - charge.

In solids, electrons move.

In liquids & gases, electrons & negative ions move.
(or positive)

How to measure electric charge:



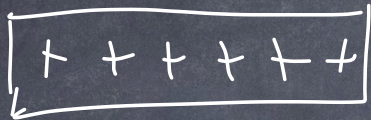
F_g : τ_{cw} clockwise torque

F_e : τ_{ccw} counter-clockwise torque

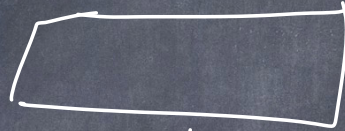


charging by conduction

1)



charged metal rod



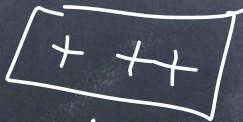
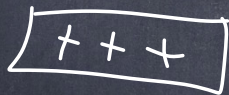
neutral metal rod

2)

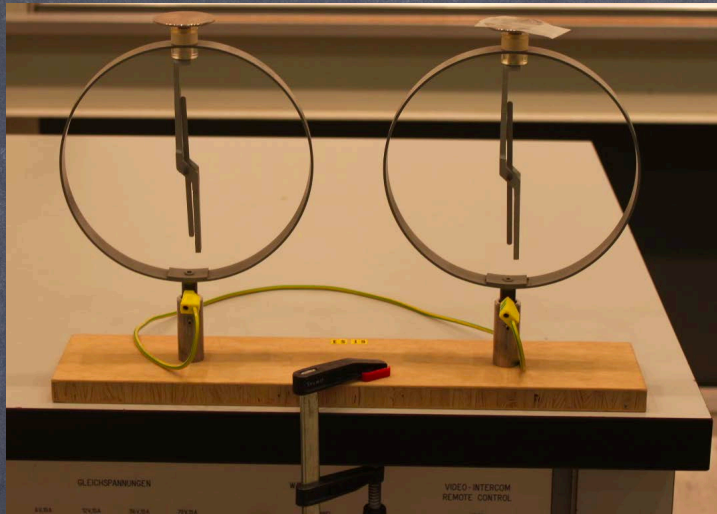


charge transferred by contact

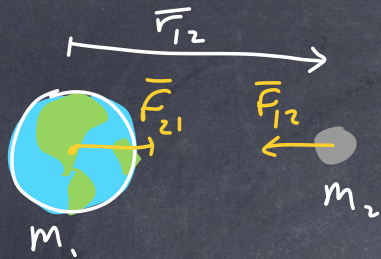
3)



both rods have a charge



What is the gravitational force between two masses:



F_{12} = force of m_1 on m_2 ,
points toward m_1
($-\hat{r}_{12}$)

(-) means
always
attractive

$$\vec{F}_{12} = -G \frac{m_1 m_2}{r_{12}^2} \hat{r}_{12}$$

G : gravitational constant, applies
to all massive objects

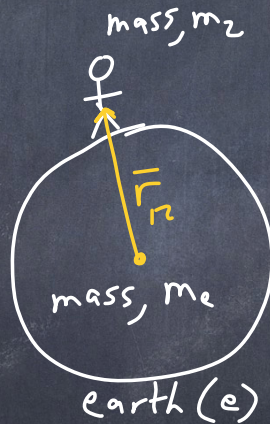
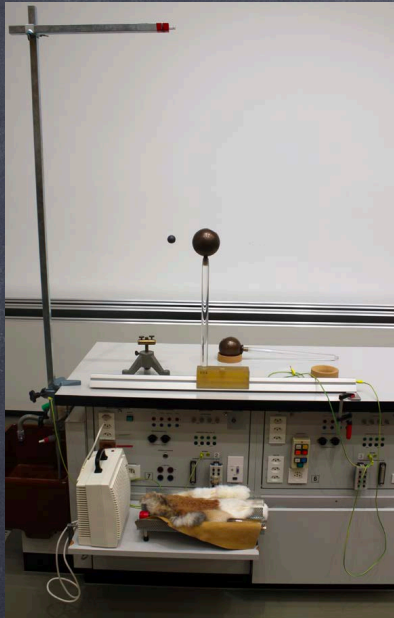
$$G = 6.672 \times 10^{-11} \frac{\text{Nm}^2}{\text{kg}^2}$$

$$\vec{F} = m \vec{g}$$

$$F = \frac{m_2 m_1 G}{r_{12}^2} (\hat{r}_{12})$$

$$\vec{g} = \frac{m_1}{r_{12}^2} G \hat{r}_{12}$$

$$g = \frac{(6.672 \times 10^{-11} \frac{\text{Nm}^2}{\text{kg}^2}) (5.98 \times 10^{24} \text{kg})}{(6370 \times 10^3 \text{m})^2} = 9.8 \text{ m/s}^2$$



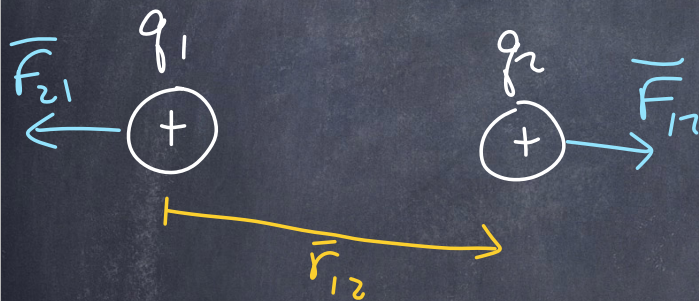
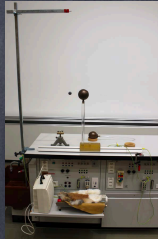
r_{12} = radius of the
earth

$$r_{12} = r_e = 6370 \text{ km}$$

$$m_e = 5.98 \times 10^{24} \text{ kg}$$

What is the electric force between 2 charges.

$$\text{Coulomb's Law: } \vec{F}_{12} = \frac{k q_1 q_2}{r_{12}^2} \hat{r}_{12}$$



$$\vec{F}_{12} = -\vec{F}_{21}$$

Newton's third law

F_{12} : "the force of q_1 on q_2 "

r_{12} : distance from q_1 to q_2

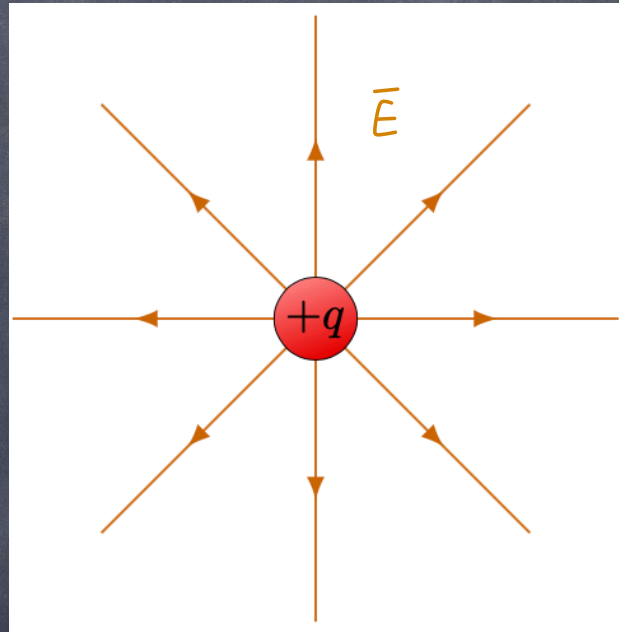
\hat{r}_{12} : unit vector of \vec{r}_{12}
 $|\hat{r}_{12}| = 1$

q_1, q_2 : amounts of charges
in coulombs (+) or (-)

$$k = 8.99 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2} \approx \frac{1}{4\pi\epsilon_0}$$

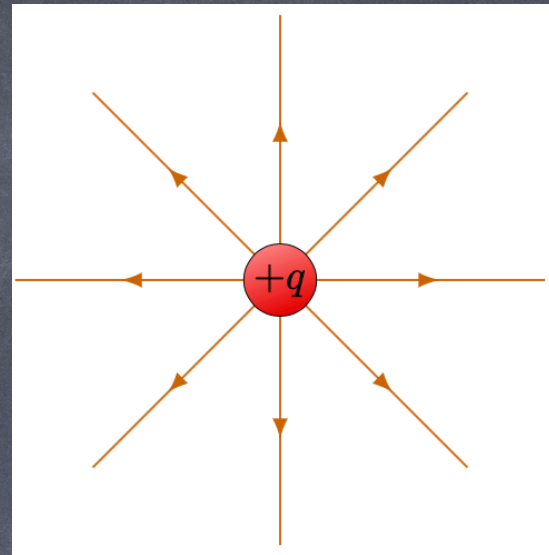
ϵ_0 = permittivity constant = $8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2$

The force comes from the electric field surrounding a charge distribution. $\vec{F} = q\vec{E}$



Rules for drawing \vec{E} -Field lines

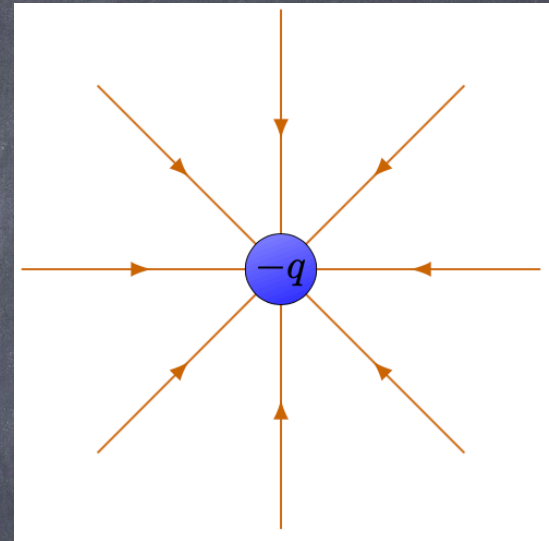
1) start on positive charges



Rules for drawing \leftarrow -field lines:

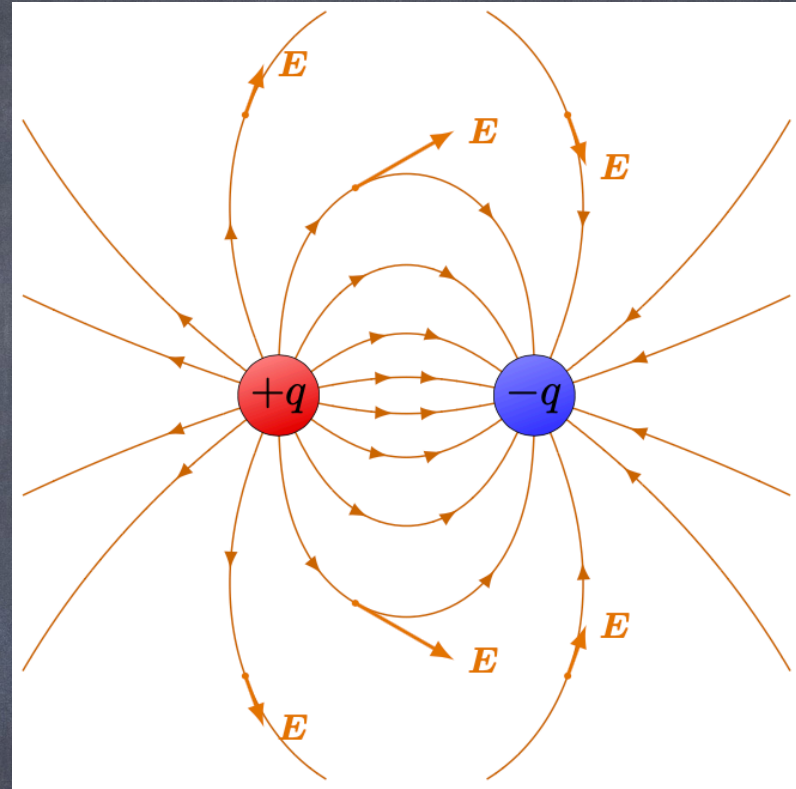
1) Start on positive charges

2) End on negative charges



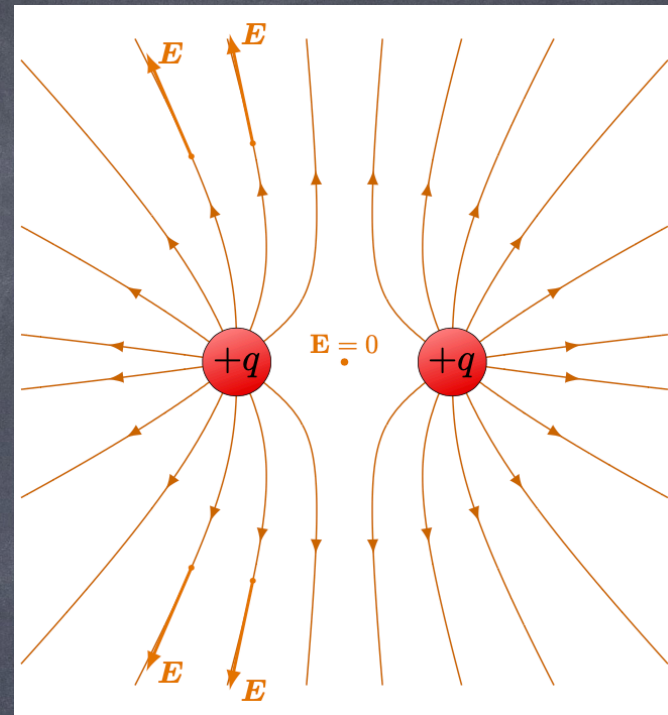
Rules for drawing \vec{E} -field lines:

- 1) Start on positive charges
- 2) End on negative charges
- 3) Lines are symmetric as they enter or leave a charge



Rules for drawing \vec{E} -field lines:

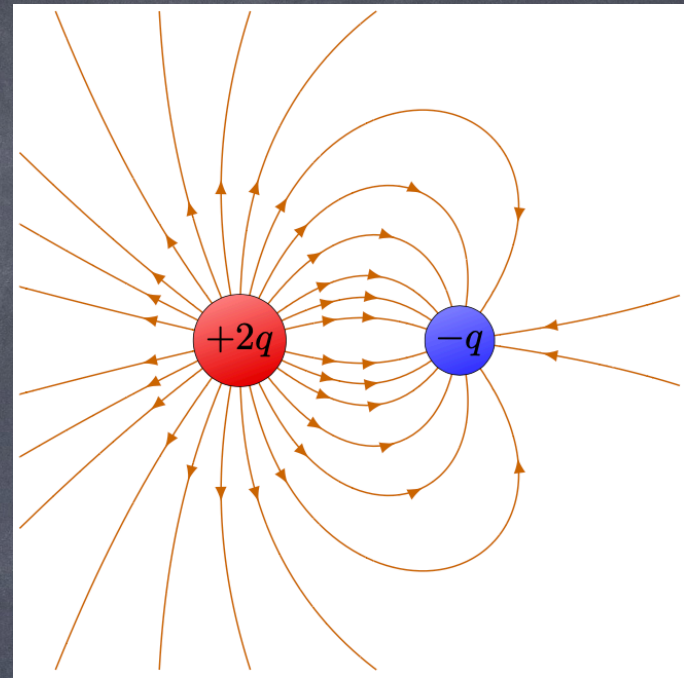
- 1) Start on positive charges
- 2) End on negative charges
- 3) Lines are symmetric as they enter or leave charge
- 4) Lines do not cross



This causes regions
of $\vec{E} = 0$

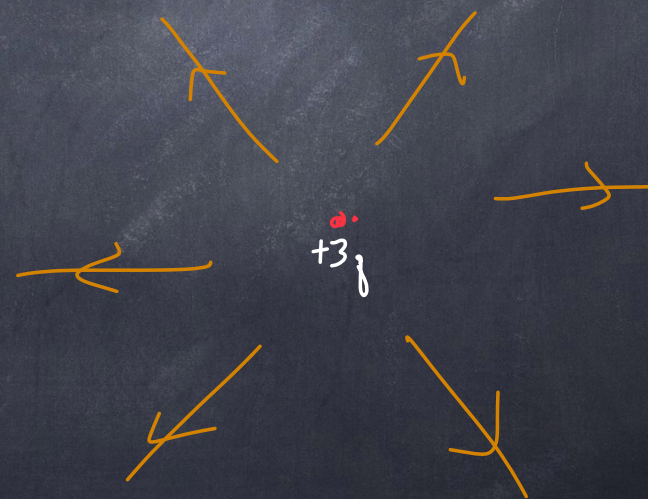
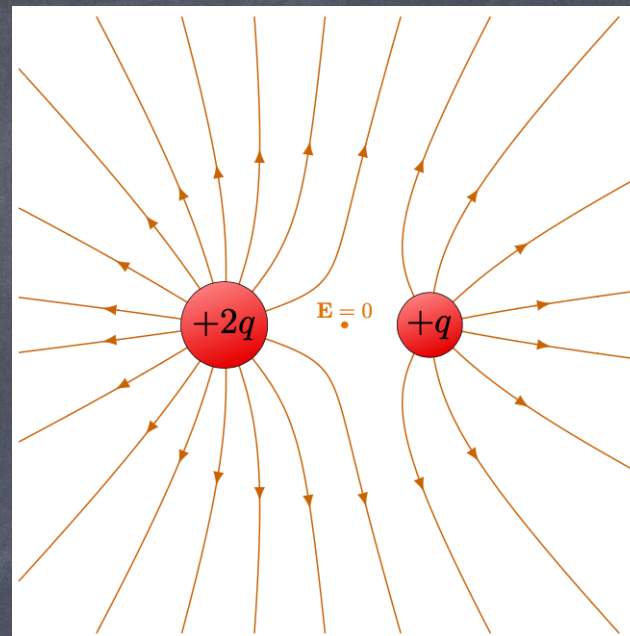
Rules for drawing \vec{E} -field lines:

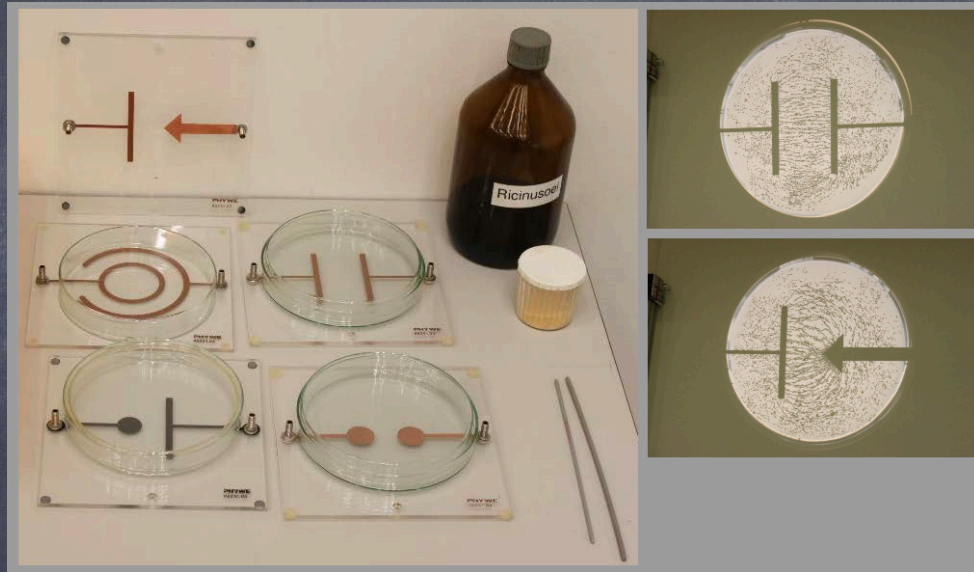
- 1) Start on positive charges
- 2) End on negative charges
- 3) Lines are symmetric as they enter or leave charge
- 4) Lines do not cross
- 5) The number of lines is proportional to the charge.
- 6) the density of lines is proportional to the magnitude of \vec{E}



Rules for drawing \vec{E} -field lines:

- 1) Start on positive charges
- 2) End on negative charges
- 3) Lines are symmetric as they enter or leave charge
- 4) Lines do not cross
- 5) The number of lines is proportional to the charge.
- 6) The density of lines is proportional to the magnitude of \vec{E}
- 7) At large distances, the \vec{E} -field lines are equally spaced as if from a single point of charge equal to the sum of charges.





Electric field: produced by electric charges

The E-field exerts a force on other charges that are nearby:

$$\vec{F} = q\vec{E} \quad \vec{E} = \frac{\vec{F}}{q}$$



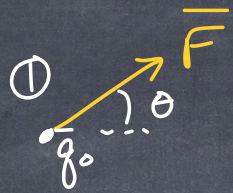
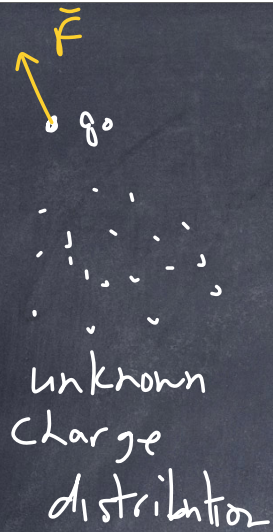
To do this, we put a test charge, q_0 , here and measure the force.

Diagram showing a source charge q_1 and a test charge q_0 . A vector \vec{r}_{10} points from q_1 to q_0 .

$$\vec{F}_{10} = \frac{kq_1q_0}{r_{10}^2} \hat{r}_{10}$$

To get \vec{E} , we divide by q_0 :
$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{kq_1}{r_{10}^2} \hat{r}_{10}$$

This is the E-field generated by q_1 at the point 0



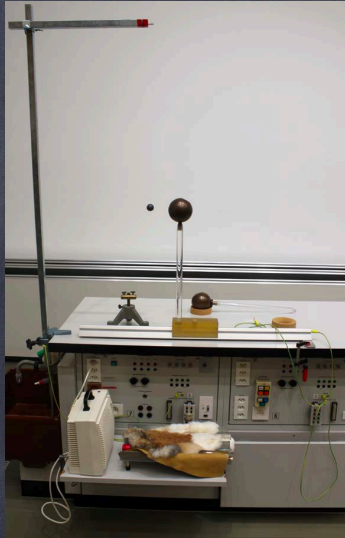
① Example: $q_0 = 10 \text{ nC}$
 We measure $\vec{F} = 10^{-5} \text{ N}$
 at $\theta = 60^\circ$

What is \vec{E} ?

$$\vec{E} = \frac{10^{-5} \text{ N}}{10 \text{ nC}} = \frac{10^{-5} \text{ N}}{10 \times 10^{-9} \text{ C}} = 1000 \frac{\text{N}}{\text{C}} \text{ at } \theta = 60^\circ$$

Important note: q_0 should be small
 so as not to change
 \vec{E} -field too much

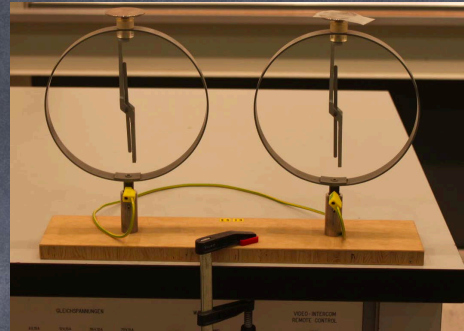
At ② + ③ different $\vec{F} \neq \vec{E}$



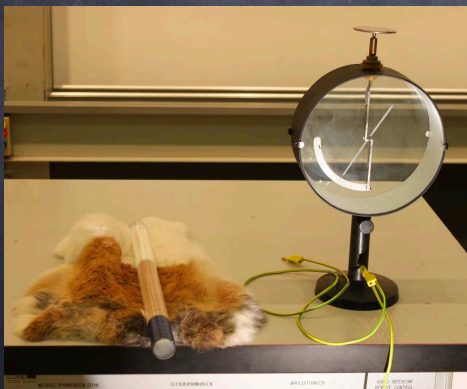
ES2



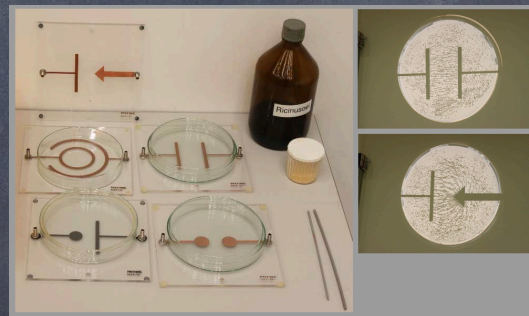
ES8



ES19



ES24



ES40