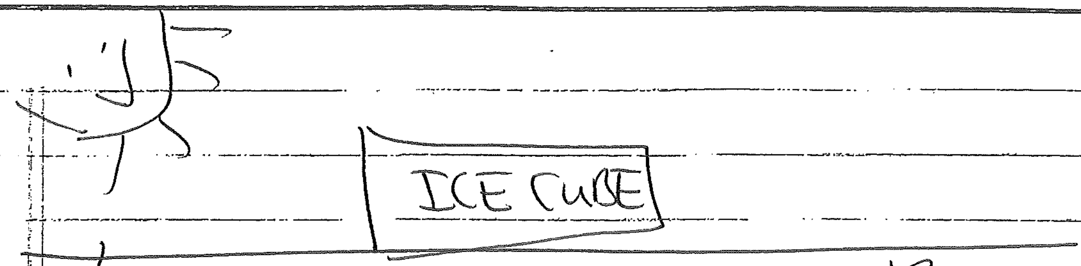


WORK done ON → System → WORK DONE BY

heat xfr. to → → heat xfr. from

1st Law of Thermodynamics

How?
- Conduction (heat through slab)
- Convection (mixing)
- Radiation (emission & absorption of light)
  - → Power $\propto$ $(\text{Temp.})^4$ ← "Sefan-Boltzmann Law"

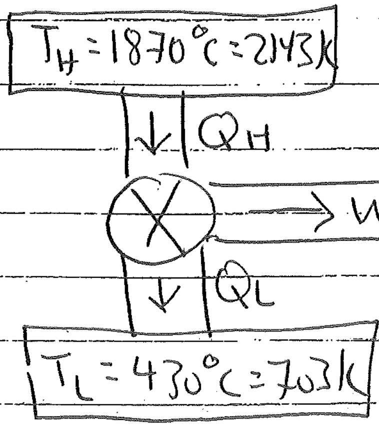
Ideal (Carnot) "engines"

Substitute Temps. (in K) for heats (Q's)

Carnot: 1832 dead

Kelvin ≈ 1848 rediscovers

EX.) One of most efficient heat engines ever built is a coal fired steam turbine electric power plant in Ohio River valley.



1^{st}: $Q_H = W + Q_L$

$$\varepsilon = \frac{get}{pay} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

$$= 1 - \frac{Q_L}{Q_H}$$

What is its max. efficiency?

$$\varepsilon_{carnot} = 1 - \frac{T_L}{T_H} = 1 - \frac{703}{2143} = 0.67 \quad (67\%)$$

What power is delivered if the plant absorbs 1.4×10^5 J per second from the hot reservoir? (NOTE: The actual efficiency of the plant is 42%)

$$\varepsilon = 0.42 = \frac{W}{Q_H} \leftarrow 1.4 \times 10^5 J$$

Can you find the heat expelled? Q_L

$\therefore W = 0.42 * Q_H = 58800$ J "per second"

58.8 kW Answer.

EX.) A freezer has a C.O.P. = 6.3.
It is advertised as using 457 kW.hr of energy per year.

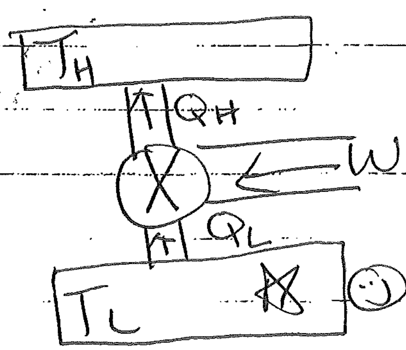
a.) On average, how much energy does it use per day?

$$\text{Power} = \frac{\text{Energy}}{\text{time}} \Rightarrow \text{Energy} = \underset{kW}{\text{Power}} * \underset{hr}{\text{time}}$$

$$457 \frac{kW \cdot hr}{yr} * \frac{1000\,W}{kW} * \frac{1\,yr}{365\,days} = 1252.1 \frac{W \cdot hr}{day}$$

$$\Rightarrow \frac{1252.1 \frac{J}{s} * (hr)}{day} * \frac{3600\,s}{hr} = 4.51 * 10^{6} \frac{J}{day}$$

b.) how much heat is removed from the freezer in a single day?

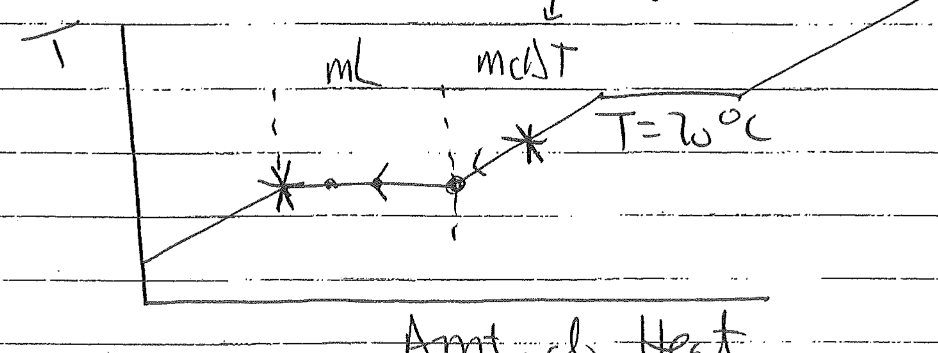


1^{st}: $Q_L + W = Q_H$

$$C.O.P. = \frac{get}{pay} = \frac{Q_L}{W} = 6.3$$

$$\therefore Q_L = 6.3 * W = 28.4 * 10^{6} \frac{J}{day}$$

c.) What is the maximum amt. of water @ 20°C that can be converted to ice @ 0°C in a single day by this freezer?



$$Q_{\text{removed from water}} = m\,c_{water}(0-20) - m\,L_{f\,water}$$

$$= -m\,(20\,c_{water} + L_{f\,water}) = -417.8\times10^{3}\,m$$

$c_{water} = 4190\ \frac{J}{kg\,K}$ $\qquad L_{f\,water} = 334\times10^{3}\ J/kg$

MUST be REMOVED

To the question: In 1 day, can remove $28.4\times10^{6}\,J$

$$\therefore\ 28.4\times10^{6} = 417.8\times10^{3}\,(m)$$

$$m = 68.1\,kg$$

Answer.

Ch. 21

All matter has mass.
Some matter has additional property of charge.

Protons $\Rightarrow$ $+1.6 \times 10^{-19}$ coulombs (C)

SI unit

Electrons $\Rightarrow$ -1.6×10^{-19} C

Opposites attract, likes repel.

In solids, protons are "locked" in nucleus.
Electrons can move.

$\Uparrow$

Easy to come by in Nature ☺

Static Electricity ☺

DEMO w/ FOILS (Electroscope)

"Charging by Induction"

Triboelectric Series (separation of charge by rubbing)

positive end
(lose electrons)

air
human skin
asbestos
rabbit fur
acetate
glass
mica
human hair
nylon
wool
cat fur
lead
silk
aluminum
paper
(0) cotton (0)
steel
wood
amber
wax
vulcanized rubber
mylar
copper & nickel
brass & silver
synthetic rubber
gold & platinum
sulfur
acetate & rayon
celluloid
polyester
polystyrene
orlon
acrylic
rubber balloon
saran
cellophane tape
polyurethane
polyethylene
polypropylene
polyvinylchloride
silicon
teflon
silicone rubber

(gain electrons)
negative end

Ancient !

Ben Franklin	1747(?)	"positive" and "negative", single fluid, all sorts of stuff!!
	1752	lightening is electrical discharge (lightening rod)
	1753	Copely Medal, Royal Society ,MA Yale & Harvard

J.J. Thompson	1897 Electron
Ernst Rutherford	1911 Nucleus (coined word 'proton')
James Chadwick	1932 Neutron

Charles Coulomb (French) 1736-1806

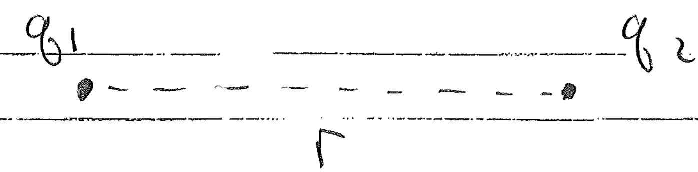
1785 $F \propto \frac{q_1 q_2}{r^2}$

$K = 8.99\times10^9 = \frac{1}{4\pi\varepsilon_0}$

Cavendish 1st
Not Published
1731-1810

Faraday 1844
"Lines of Force"

Coulomb's Law



$$|\vec{F}_{q_1 q_2}| = \frac{k|q_1||q_2|}{r^2} \qquad k = 8.99 \times 10^9 \ \frac{Nm^2}{C^2}$$

$$k = \frac{1}{4\pi\varepsilon_0}$$

ε_0: permittivity of free space

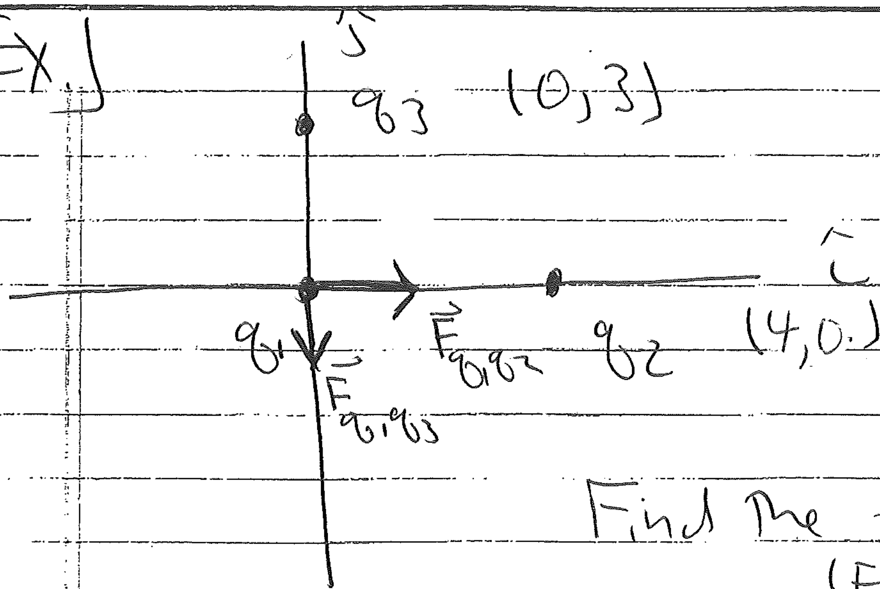
Assign direction !!!

Opposites attract
Likes repel

Recall Newton: Interaction characterized by a single force experienced from two different perspectives.

Electric force $\Rightarrow$ "Spooky" || Action at a distance

Ex.)



SI units

$q_1 = -5\ C$
$q_2 = +10\ C$
$q_3 = -8\ C$

Find the force on q_1.
(Electric)

Charges are "nailed down" ☺

$\vec{F}_{q_1q_2}$ is force on q_1 due to q_2.

$$|\vec{F}_{q_1q_2}| = \frac{k|q_1||q_2|}{r_{12}^2} = \frac{8.99\times10^9(5)(10)}{4^2}$$

$$= 2.81\times10^{10} \text{ newtons}$$

$$\vec{F}_{q_1q_2} = +2.81\times10^{10}\ \hat{i}$$

"Superposition"

$\vec{F}_{q_1q_3}$ is force on q_1 due to q_3.

$$|\vec{F}_{q_1q_3}| = \frac{k|q_1||q_3|}{r_{13}^2} = 4.0\times10^{10} \text{ newtons}$$

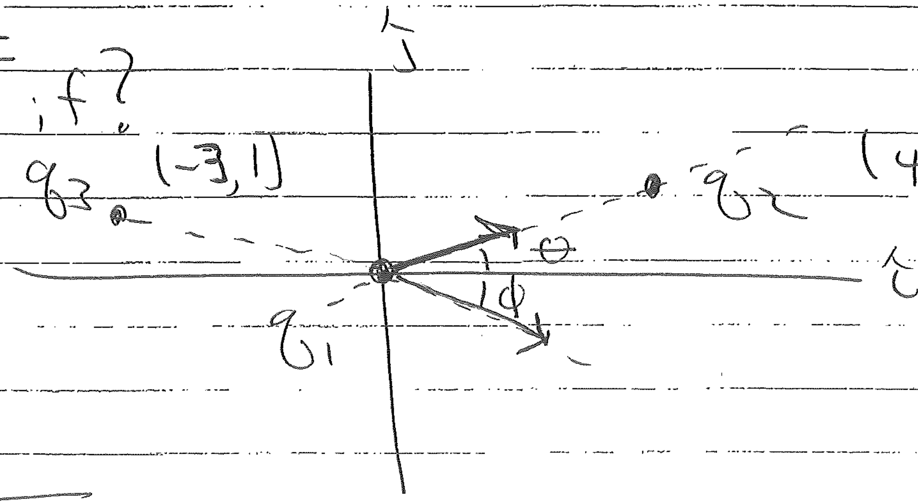
$$\vec{F}_{q_1q_3} = -4\times10^{10}\ \hat{j}$$

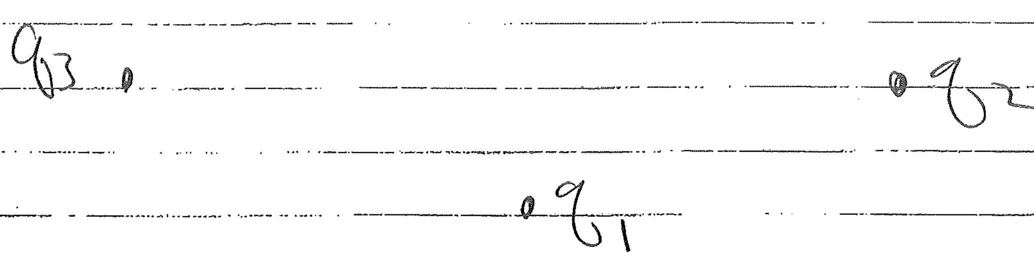
$\therefore \vec{F}_{\substack{on\\q_1}} = \vec{F}_{q_1q_2} + \vec{F}_{q_1q_3} = 2.81\times10^{10}\,\hat{i} - 4\times10^{10}\,\hat{j}$

OR report as a magnitude and direction

$|\vec{F}_{\substack{on\\q_1}}|$

What if?





A Paradigm Shift:

q_1 q_2

$$|\vec{F}_{q_1q_2}| = \frac{k|q_1||q_2|}{r^2}$$

Spooky Force

Hmmmm... Suppose q_1 disturbs all the space around it. *

q_2 then interacts w/ that "disturbed" space.

Characterize that disturbance with a "VECTOR FIELD" ...

Define: The electric field produced by a point charge

$q \bullet \xrightarrow{\quad r \quad} *$ observation point $\qquad |\vec{E}_{\text{pt. charge}}| = \dfrac{k|q|}{r^2}$

Radially away from positive charges.
Radially toward negative charges.

Michael Faraday, "Lines of Force", ~1844

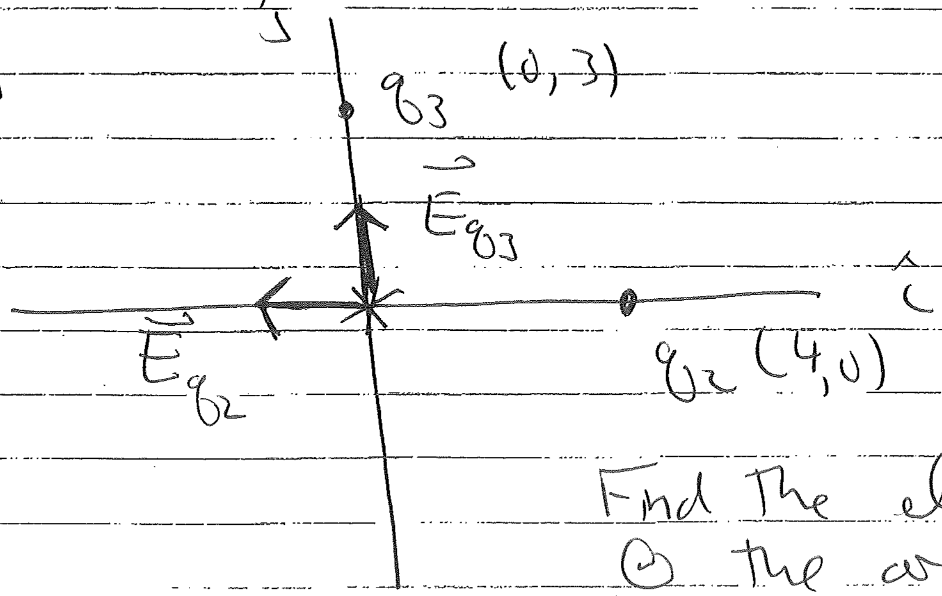
Revisit:

$q_1 \bullet - - - - - - - \bullet q_2$

$$|\vec{F}_{q_1 q_2}| = \frac{k|q_1||q_2|}{r^2} = \underbrace{\left[\frac{k|q_1|}{r^2}\right]}_{E_{q_1} \text{ @ location of } q_2} q_2$$

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

EX.)



$q_2 = 10\,C$
$q_3 = -8\,C$

Find the electric field @ the origin.

$$\vec{E}_{@\,\text{origin}} = \vec{E}_{q_2\,@\,\text{origin}} + \vec{E}_{q_3\,@\,\text{origin}}$$

$$\vec{E}_{q_2\,@\,\text{origin}} = -\frac{k|q_2|}{4^2}\,\hat{i} = -5.62 \times 10^9\,\hat{i}$$

$$\vec{E}_{q_3\,@\,\text{origin}} = +\frac{k|q_3|}{3^2}\,\hat{j} = 7.99 \times 10^9\,\hat{j}$$

$$\therefore\ \vec{E}_{@\,\text{origin}} = -5.62 \times 10^9\,\hat{i} + 7.99 \times 10^9\,\hat{j}$$

What would be the force on

a $-5C$ charge placed @ the origin?

$$\vec{F} = q_0 \vec{E} = (-5)(-5.62\times10^{9}\hat{i} + 7.99\times10^{9}\hat{j})$$
$$= +2.81\times10^{10}\hat{i} - 4\times10^{10}\hat{j}$$

$\boxed{\checkmark}$ consistent