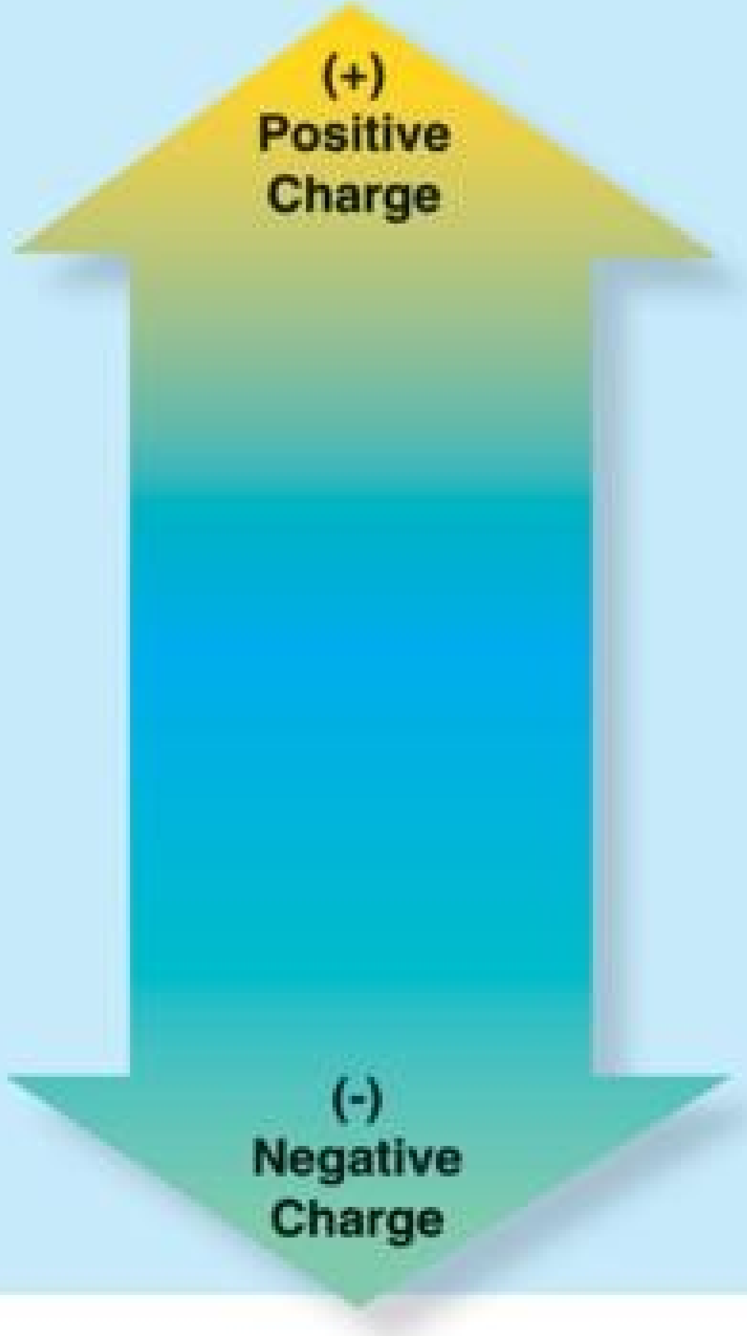
Electrostatics

Nothing new here, we could just skip this unit...

Well, maybe not

Statics Activity
Can you charge up objects to show:

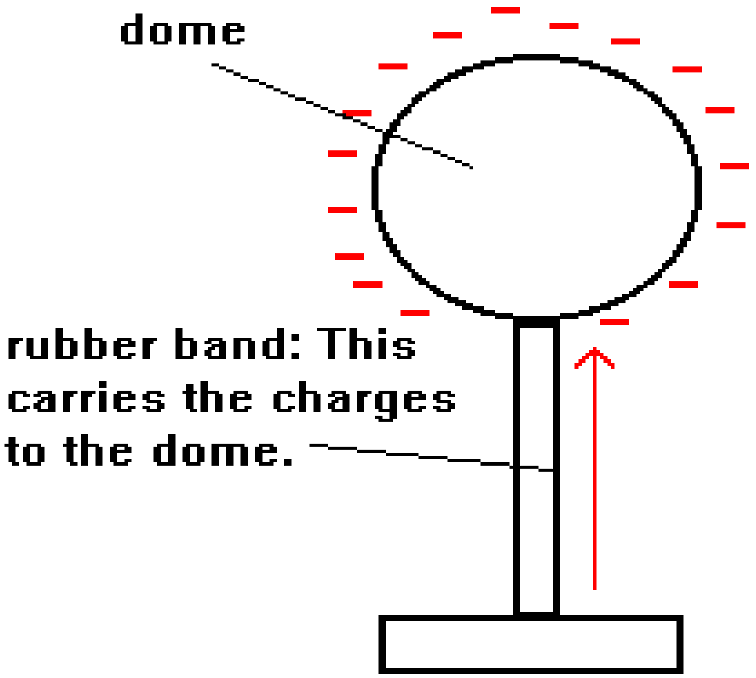
- The electroscope charge by conduction?
- The electroscope charge by induction?
- Two strips repel each other?
- Two strips attract each other?
- A strip attract a stream of water?



Air
Human skin
Rabbit fur
Glass
Human hair
Nylon
Wool
Silk
Aluminum
Paper
Cotton
Steel
Wood
Hard rubber
Nickel, copper
Brass, silver
Gold, platinum
Acetate fiber (Rayon)
Polyester
Cling film
Polyethylene
PVC
Silicon
Teflon

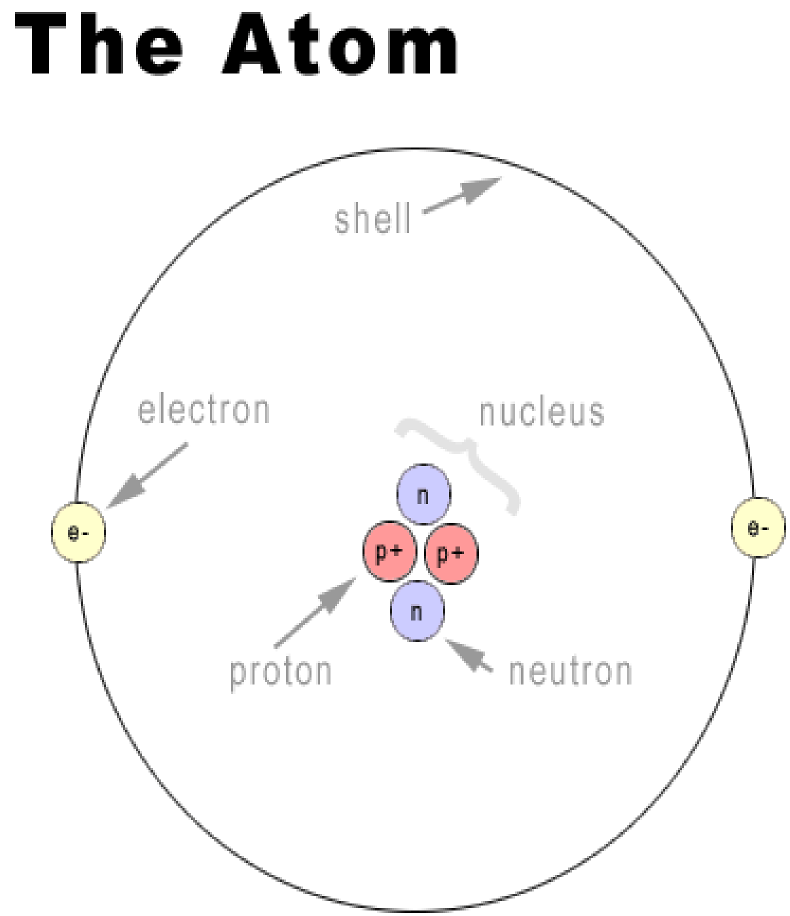
Van der Graaf

- If we hold on to the dome, we can become charged
- Since our hairs all have the same charge, they repel
- Conversely, opposites attract



Static Charge

- Every atom of matter is made of a dense, +ve nucleus surrounded by -ve electrons.
- We can charge by conduction, induction, or friction



Static discharge

How much?

- Electrons and protons have the same charge magnitude:

  $e=1.6\times10^{-19}$ C
- Ex: a bolt of lightning transfers 10 C in a fraction of a second. How many electrons is this?

$$n=\frac{Q}{e} = \frac{10C}{1.6\times10^{-19}\ C/e^-} = 6.25\times10^{19}$$

Electric Force

- Recall gravitation: $F_g = \frac{GMm}{r^2}$

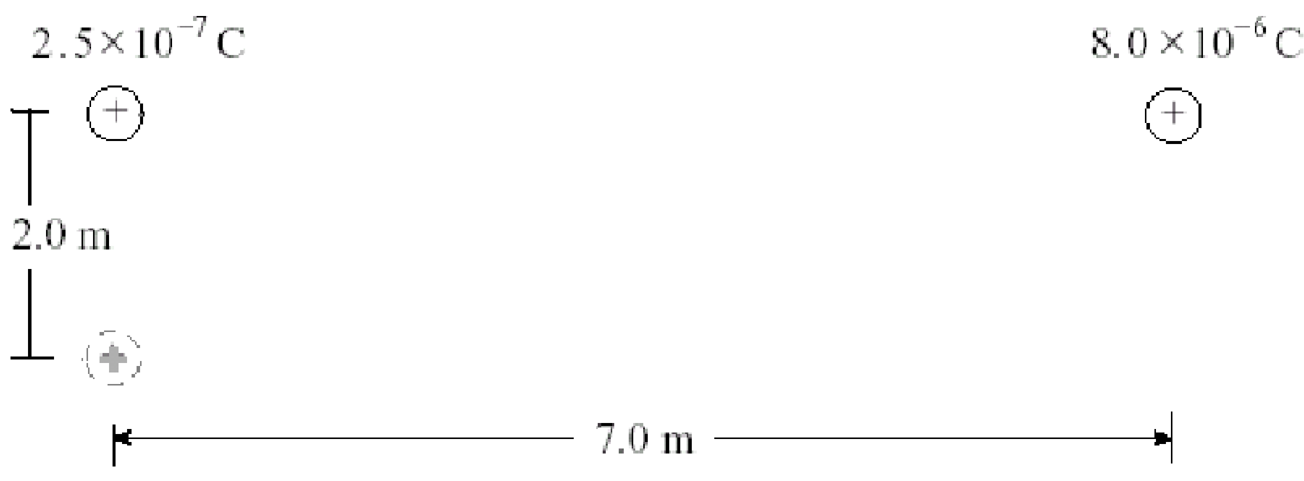
- Very similar to our Fg formula, if we replace “mass” with “charge” we have:

$$F_e = \frac{kQq}{r^2}$$

- Where:
- Q and q are the two charges in Coulombs
- $k=8.99\times10^9$ Nm^2/C^2 and
- r is the distance between their centers

Ex 1:Find F

- What is the net force acting on a 8.0μC charge from the smaller 0.25 μC charge?



$$F_1 = \frac{kQq}{r^2}$$

$$F_1 = \frac{9\times10^9\ {Nm^2}/{C^2}\ 2.5\times10^{-7}\,C\cdot8.0\times10^{-6}\,C}{(7m)^2}$$

$$F_1 = 0.00037\,N$$

Electric Field

- Also related to gravitational field g=F/m
- E=F/q so:

$$E = \frac{kQ}{r^2}$$

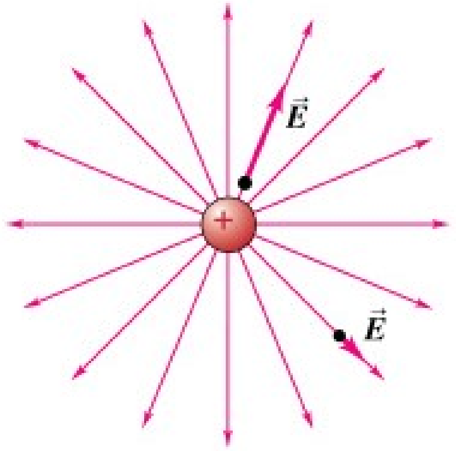
- Note: this is a vector, so we can find the field at any point relative to two or more charges

Exercises

- p. 198 #20-21
- Activity

Direction?

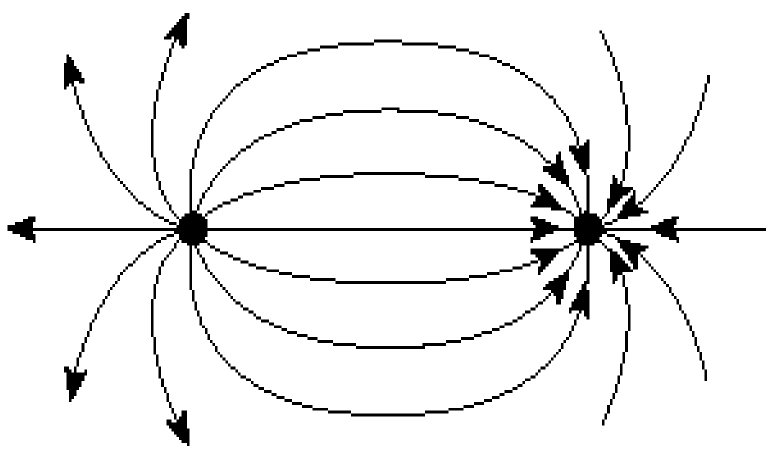
- The direction of electric field is defined as the direction of force on a positive test charge
- Note: field lines never cross!



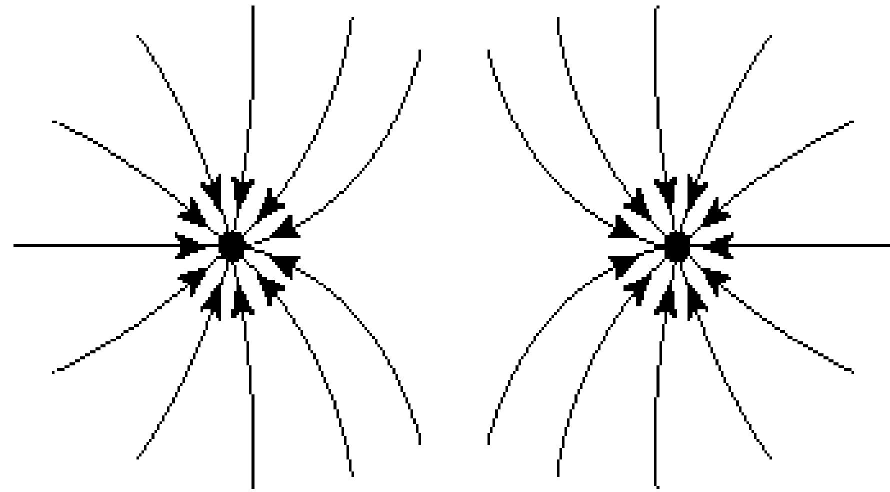
(a) A single positive charge
(compare Figure 21.16)

Which of the following shows the electric field for two opposite unequal point charges?

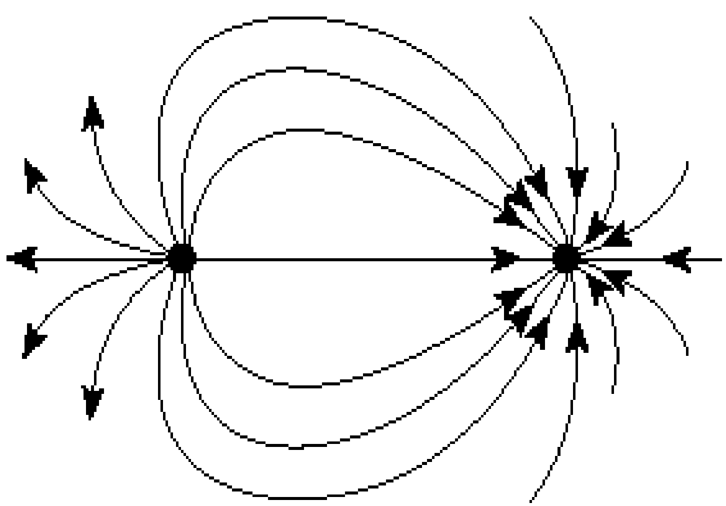
A.



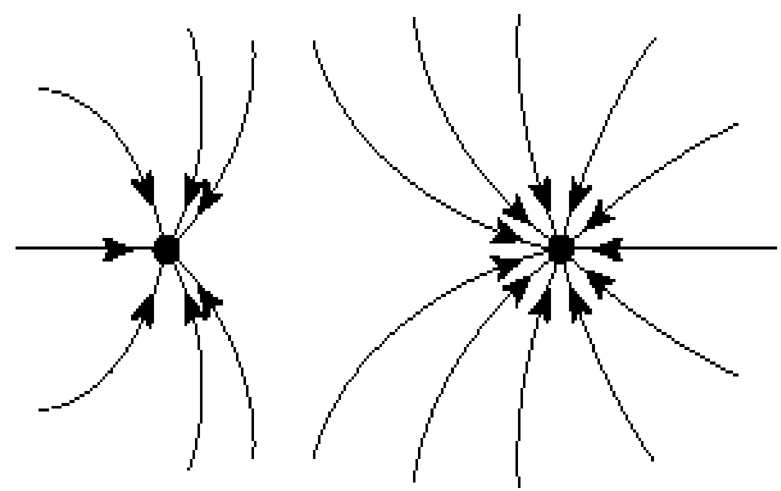
B.

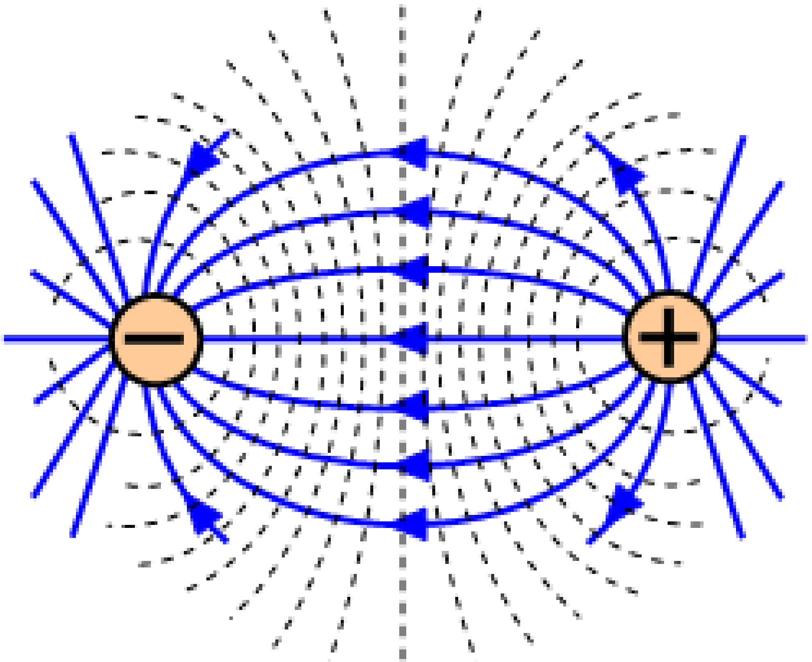


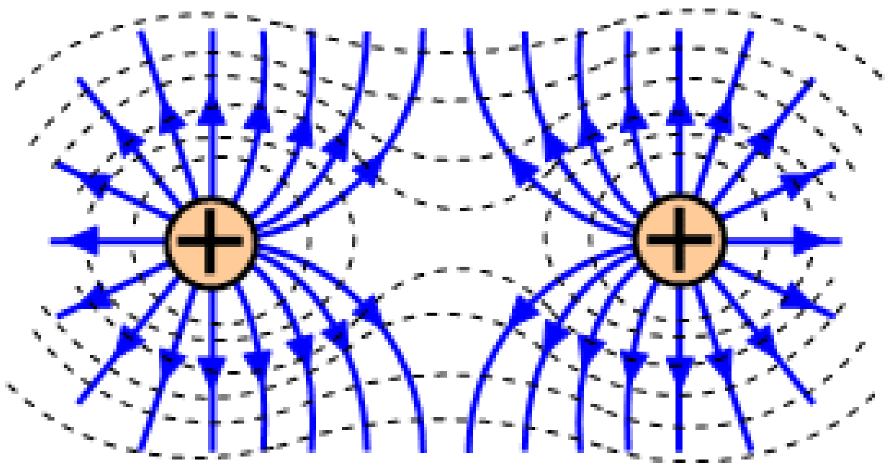
C.

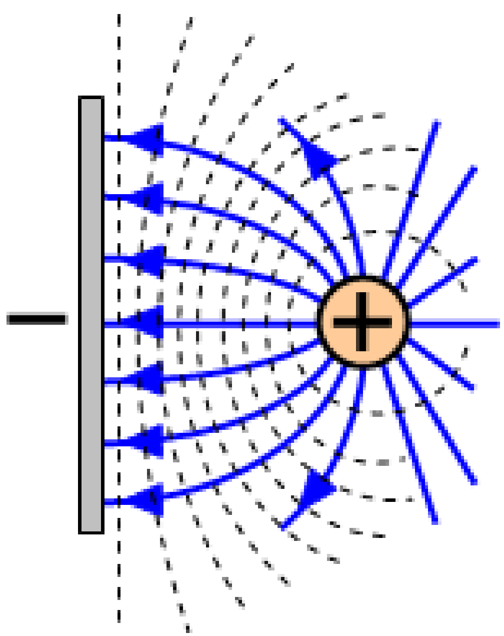


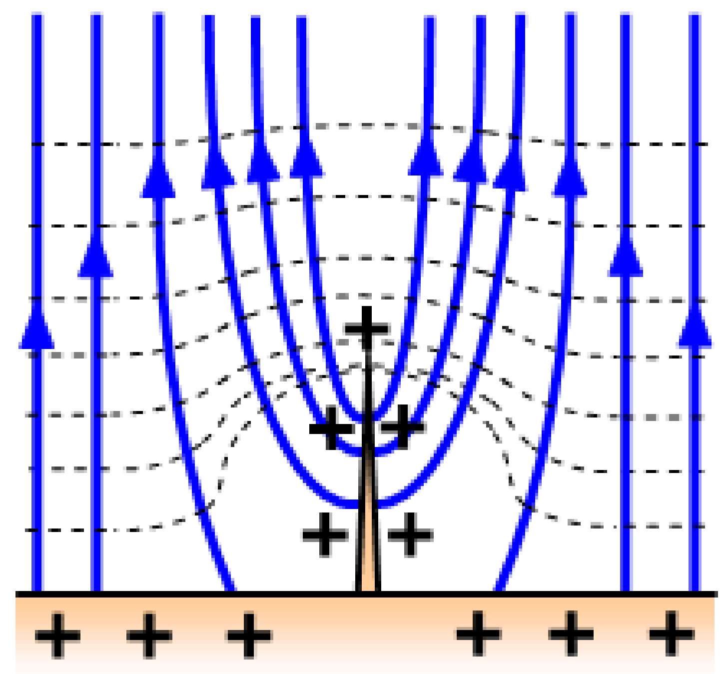
D.

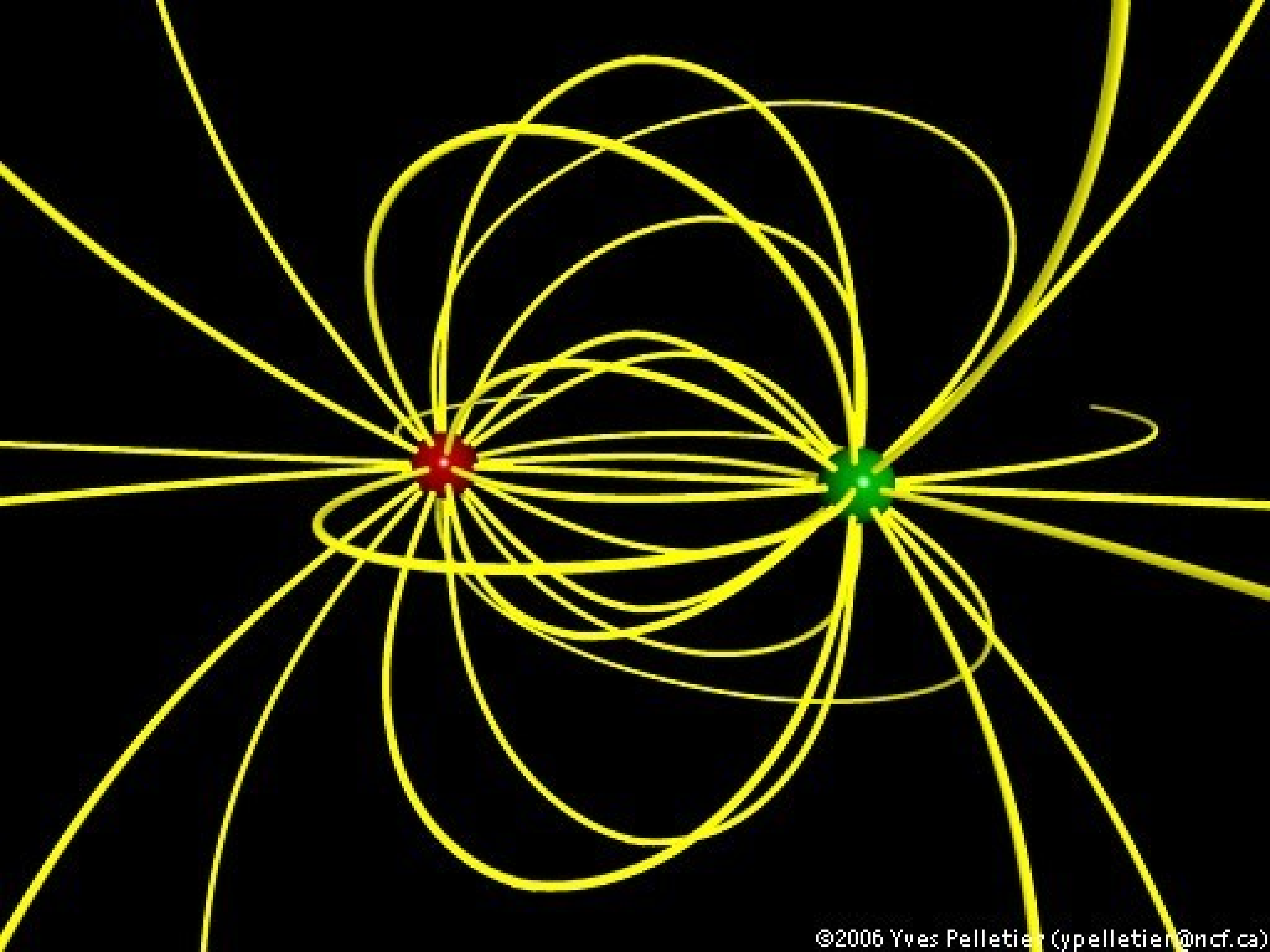












Ex 2:Find E

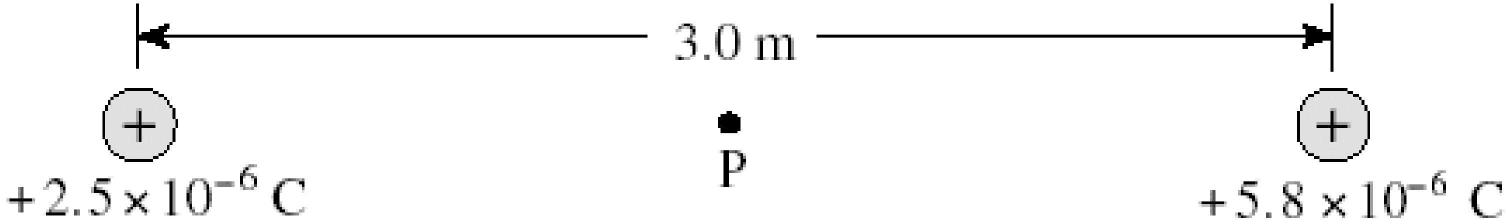
- What is the electric field 0.25 m to the right of a 0.5 μC charge?

$$E = \frac{kQ}{r^2}$$

$$E = \frac{9\times10^{9}\, Nm^2/C^2\,(0.5\times10^{-6}\,C)}{(0.25m)^2}$$

$$E = 72\, kN/C\ Right$$

Two positive point charges are placed 3.0 m apart as shown.



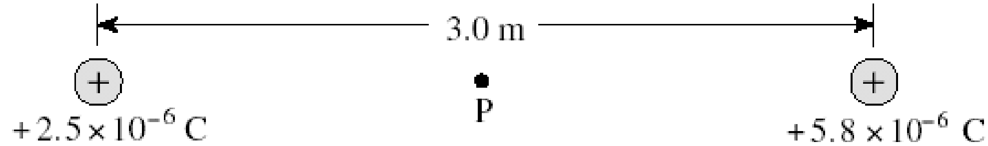
What is the magnitude of the electric field at point P midway between the two charges?

$$E = \frac{kQ}{r^2} \quad E_1 = \frac{9\times10^9\ Nm^2/C^2 \cdot 2.5\times10^{-6}C}{(1.5m)^2}$$

$$E_1 = 10\,kN/C \rightarrow$$

$$E = \frac{kQ}{r^2}$$

Two positive point charges are placed 3.0 m apart as shown.



What is the magnitude of the electric field at point P midway between the two charges?

$$E_2 = \frac{9\times10^9\ Nm^2/C^2 \cdot 5.8\times10^{-6}\,C}{(1.5m)^2}$$

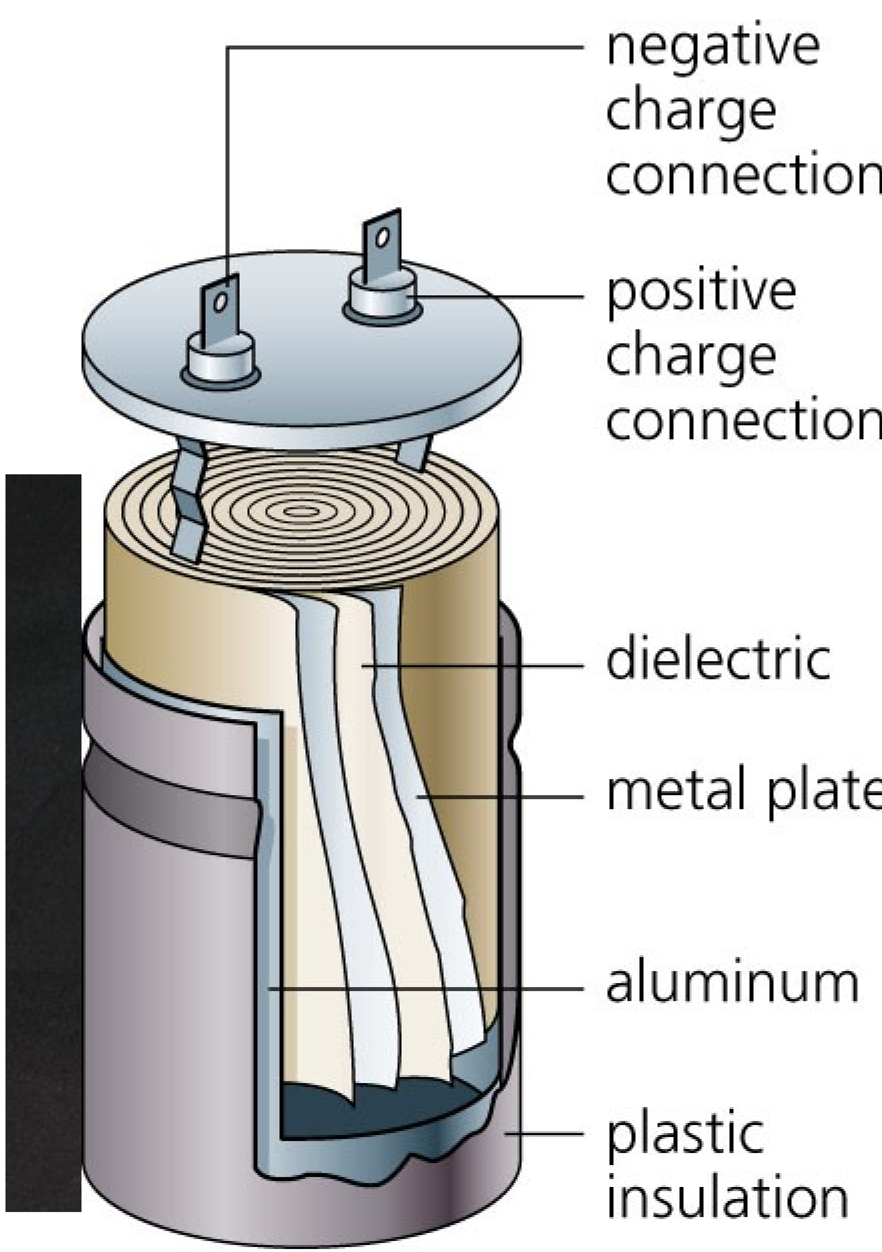
$$E_2 = 23\,kN/C \leftarrow$$

$$E = E_1 + E_2 = 10\,kN/C + (-23\,kN/C)$$

$$E = E_1 + E_2 = 13\,kN/C \leftarrow$$

Exercises

- p. 198 #20-21

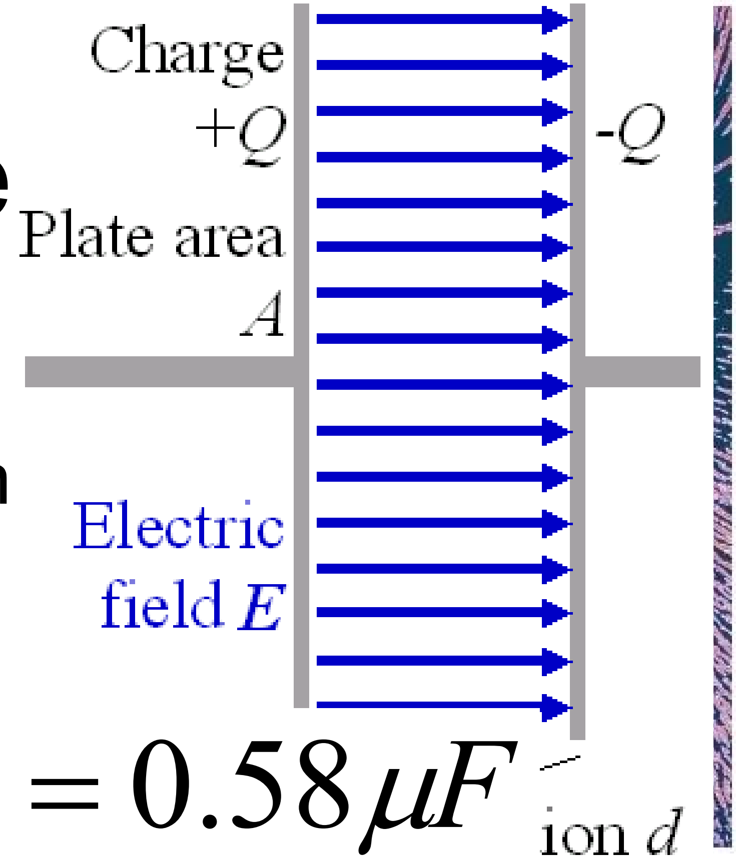

negative
charge
connection
positive
charge
connection
dielectric
metal plate
aluminum
plastic
insulation


ELNA
CE-W
75V 8000µF
BLACK-NEG

Get him to the Greek!

Greek Letter		Name	Equivalent	Sound When Spoken
Α	α	Alpha	A	al-fah
Β	β	Beta	B	bay-tah
Γ	γ	Gamma	G	gam-ah
Δ	δ	Delta	D	del-tah
Ε	ε	Epsilon	E	ep-si-lon
Ζ	ζ	Zeta	Z	zay-tah
Η	η	Eta	E	ay-tay
Θ	θ	Theta	Th	thay-tah
Ι	ι	Iota	I	eye-o-tah
Κ	κ	Kappa	K	cap-ah
Λ	λ	Lambda	L	lamb-dah
Μ	μ	Mu	M	mew
Ν	ν	Nu	N	new
Ξ	ξ	Xi	X	zzEye
Ο	ο	Omicron	O	om-ah-cron
Π	π	Pi	P	pie
Ρ	ρ	Rho	R	row
Σ	σ	Sigma	S	sig-ma
Τ	τ	Tau	T	tawh
Υ	υ	Upsilon	U	oop-si-lon
Φ	ϕ	Phi	Ph	figh or fie
Χ	χ	Chi	Ch	kigh
Ψ	ψ	Psi	Ps	sigh
Ω	ω	Omega	O	o-may-gah

More Electric Fie

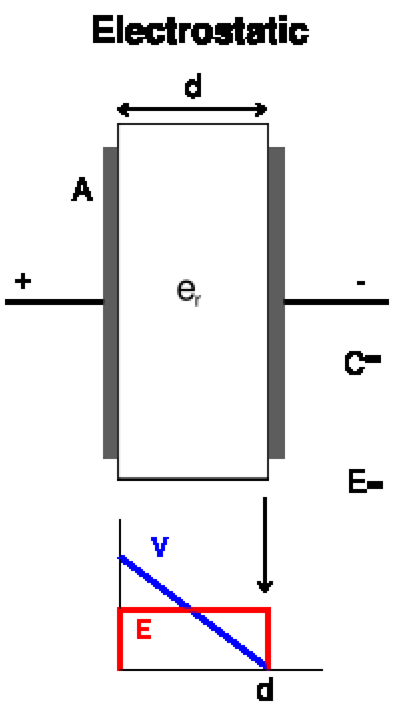


- Also related to voltage
- If you cross a voltage V in distance d we get

$$C = \frac{q}{V} = \frac{3.5\times10^{-6}}{6} = 0.58\,\mu F$$

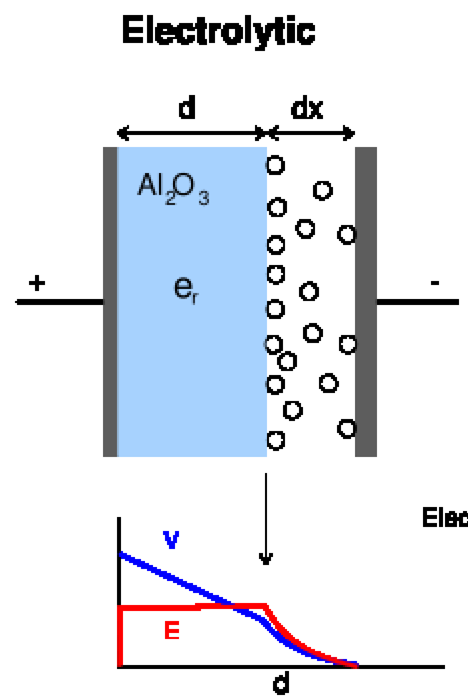
- Ex 1: A capacitor is connected to a 6V battery. What is the capacitance if it stores a charge of 3.5 μC?

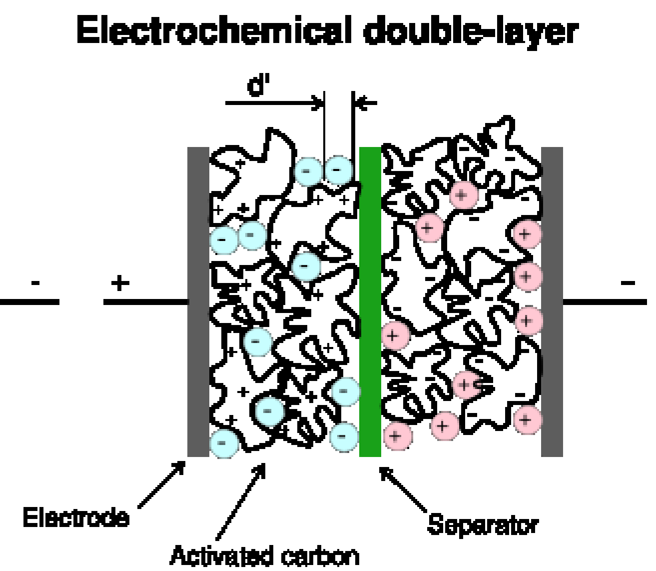
Supercapacitors!

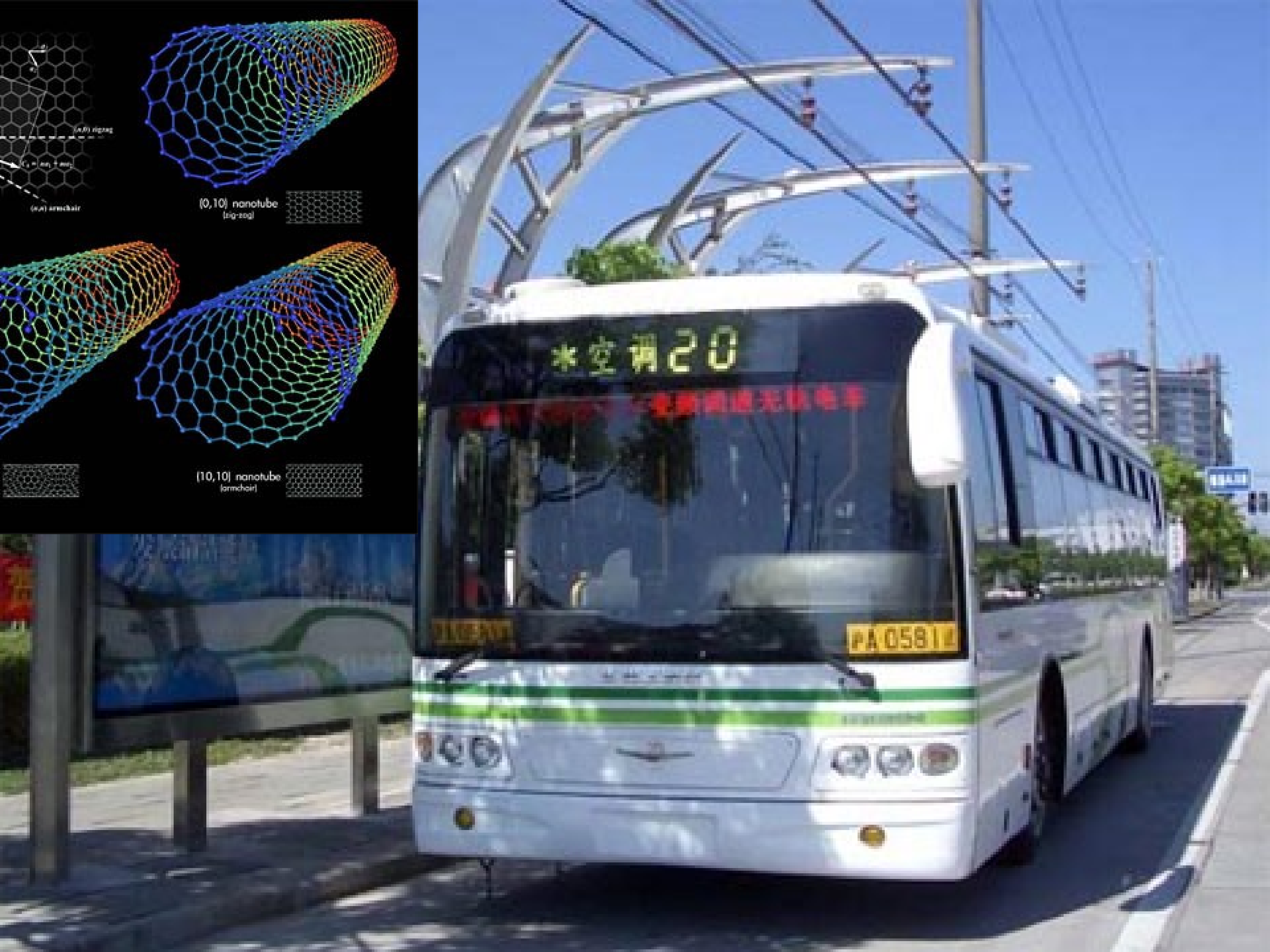


$$C = \frac{e_r e_0 A}{d}$$

$$E = \frac{V}{d}$$






(n,0) zigzag
(n,n) armchair
(0,10) nanotube
(zig-zag)
(10,10) nanotube
(armchair)
空调20

How much charge?

- The capacitor in this bus charges at 1 MW of Power at 240V for 10 seconds at each bus stop. First: how much energy?

$$P = \frac{E}{t}$$

$$E = Pt$$

$$E = 10^6 W \cdot 10 s = 10^7 J$$

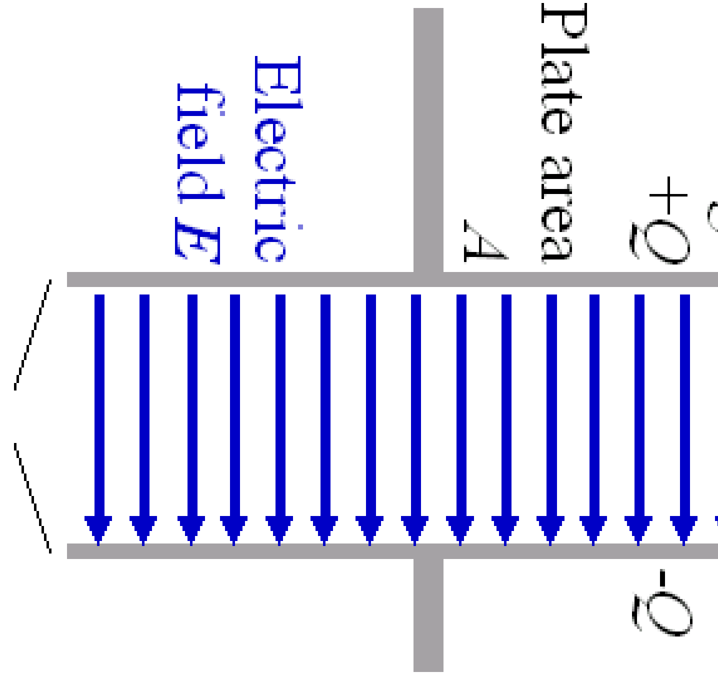
How much charge?

- The supercapacitor charges at a MW of Power at 240V for 10 seconds at each bus stop.

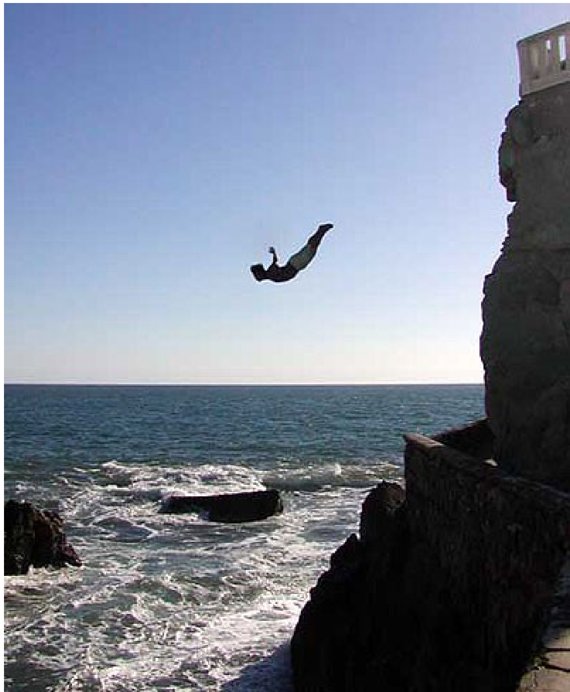
$$V = \frac{W}{q}$$

$$q = \frac{W}{V} = \frac{10^7 J}{240 J / C} = 42000C\,?!$$

- How high?
  - Potential is energy per unit charge
  - Charges that "fall" across this potential difference lose potential energy and gain kinetic energy



$$V = \frac{W}{q}$$



$$\frac{\Delta E_p}{weight} = height$$

Capacitor activity

- Use a voltmeter to set a power supply at 2.7V
- Measure current of capacitor as it charges, every 10sec
- Sketch a graph of its charging curve

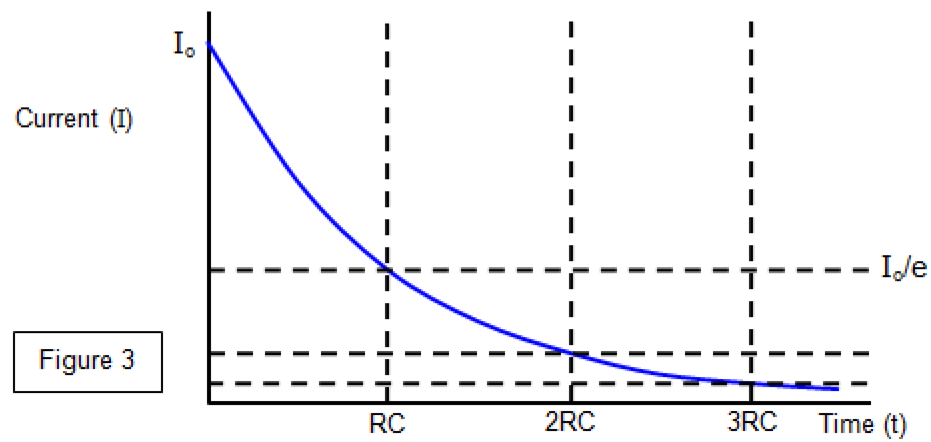


Figure 3

Cathode Ray Tube (CRT)

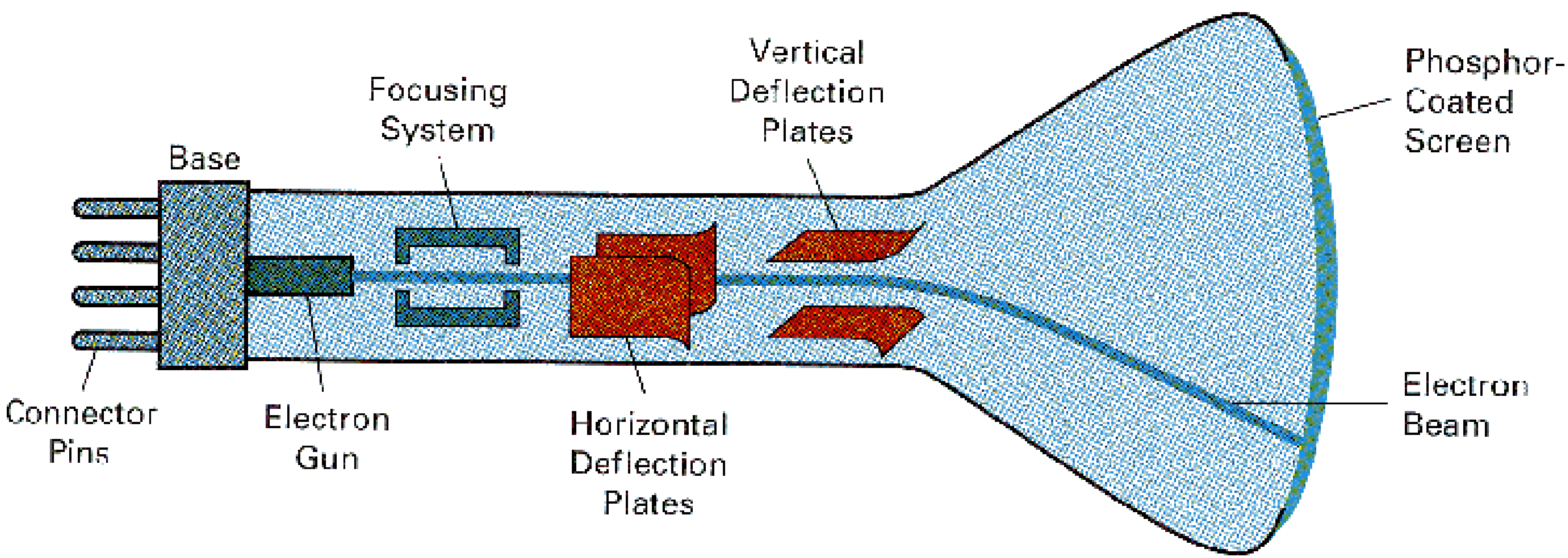
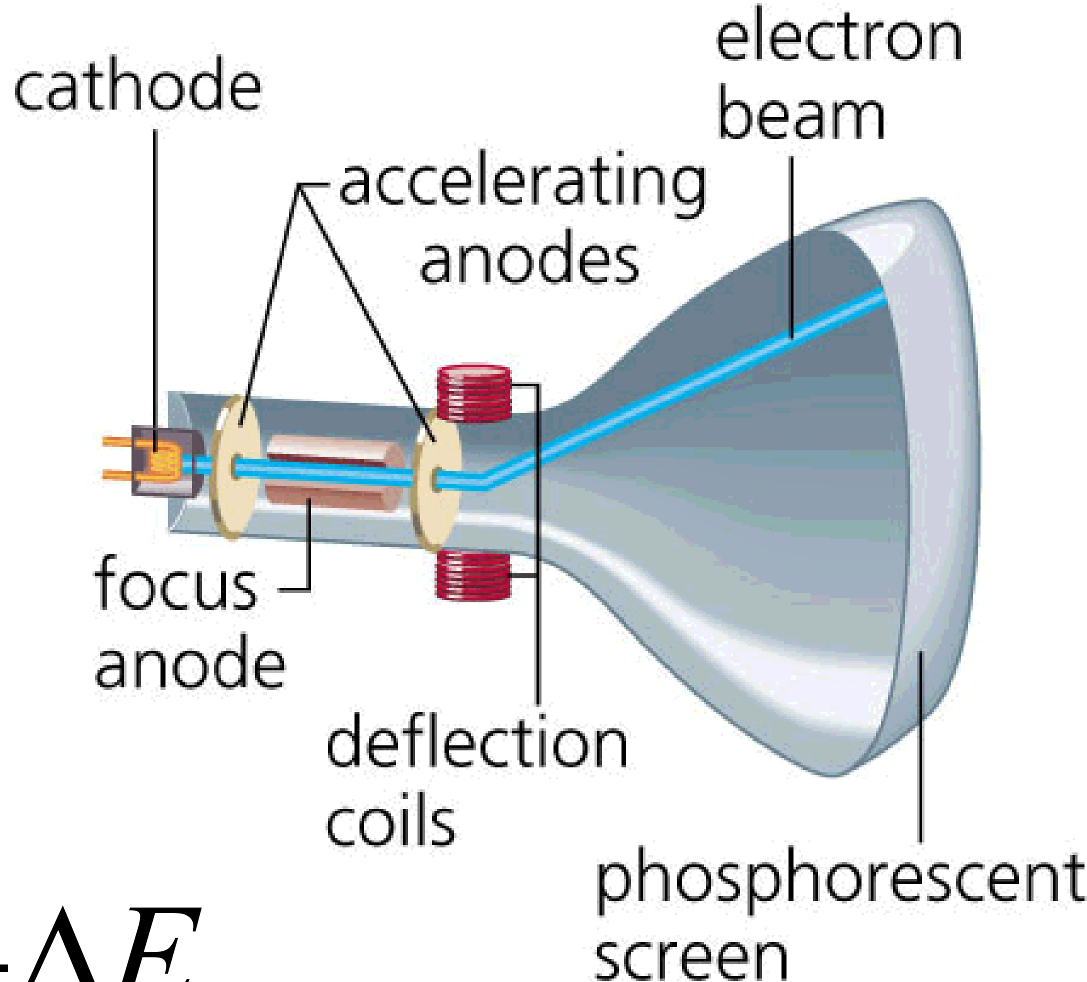


Figure 2.4 from H&B

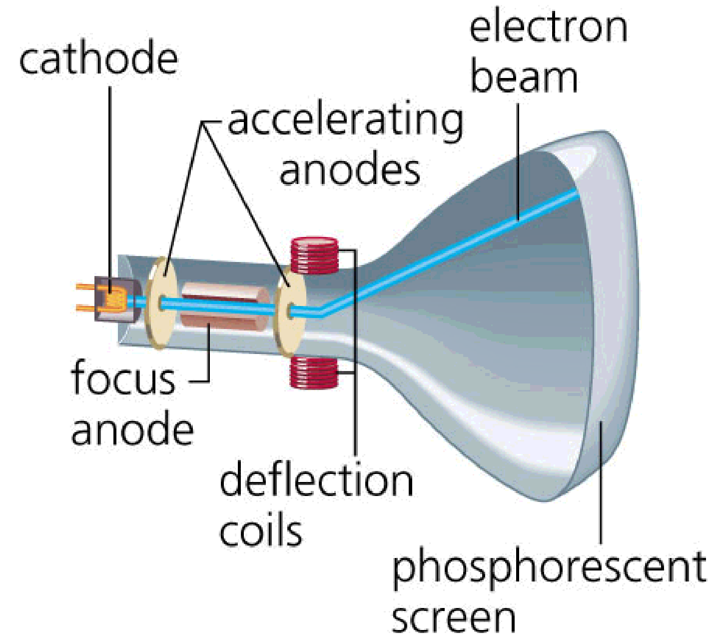
Cathode Ray Tube (AKA electron gun)

- Ex 1: what is the accelerating potential (AKA Voltage) if the electrons are accelerated to 0.1c?



$$W = qV = -\Delta E_k$$

$$qV = -\frac{1}{2}mv^2$$



$$V = -\frac{mv^2}{2q}$$

$$V = -\frac{9.1\times10^{-31}kg\cdot\left(3\times10^{7}\,m/s\right)^2}{2\cdot\left(-1.6\times10^{-19}C\right)}$$

$$V = 2.6kV$$

- Deflection
  - The greater the deflection potential, the greater the deflection

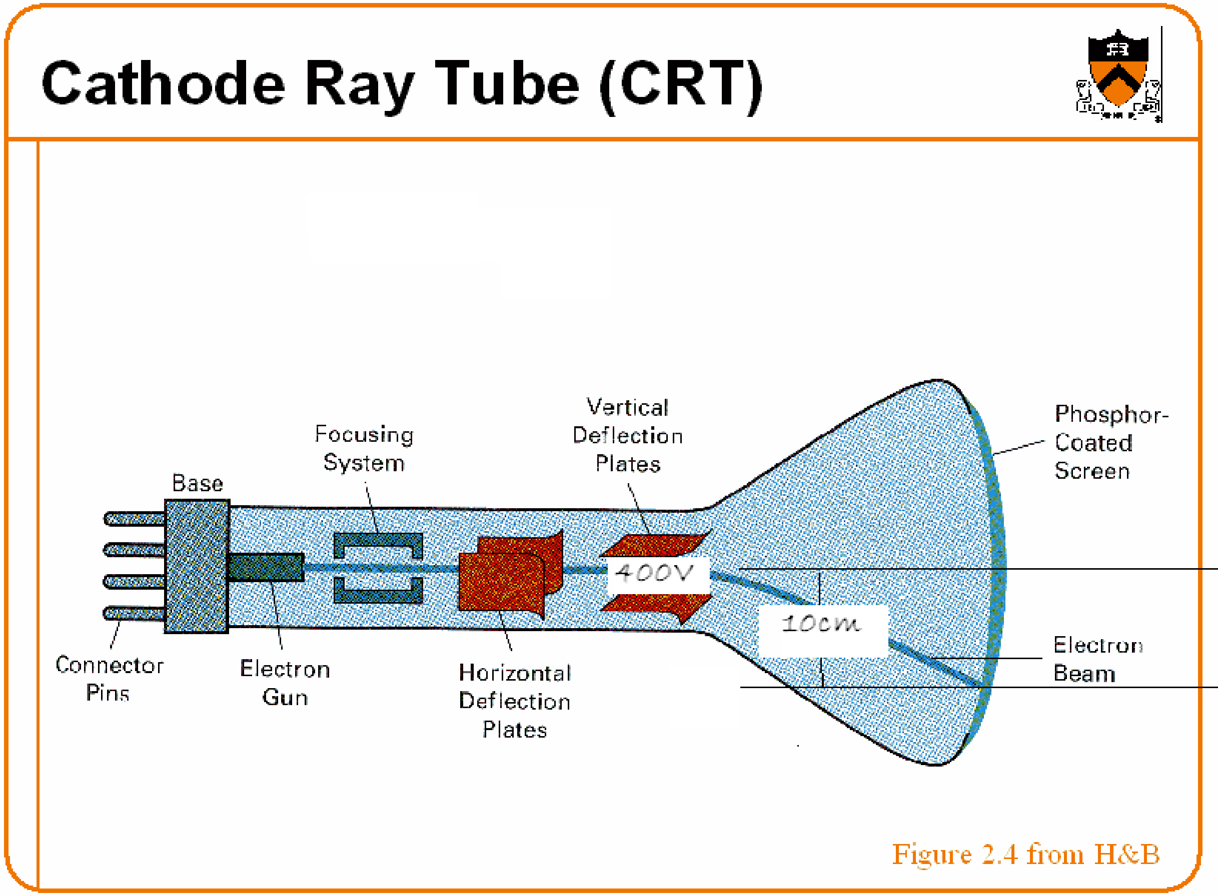


Figure 2.4 from H&B

$$d \propto V$$

- Ex 2: How much deflection will we observe if we decrease the deflection potential to 100V?

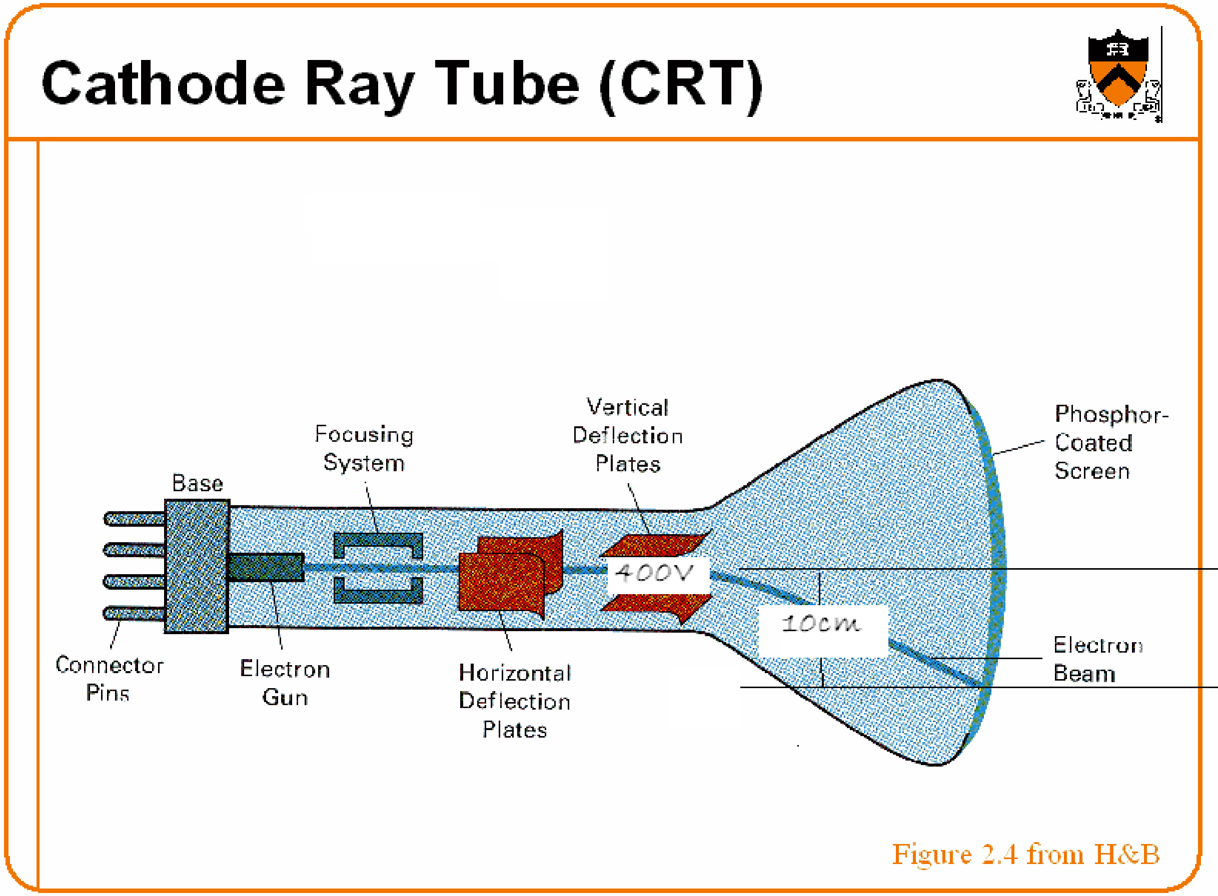


Figure 2.4 from H&B

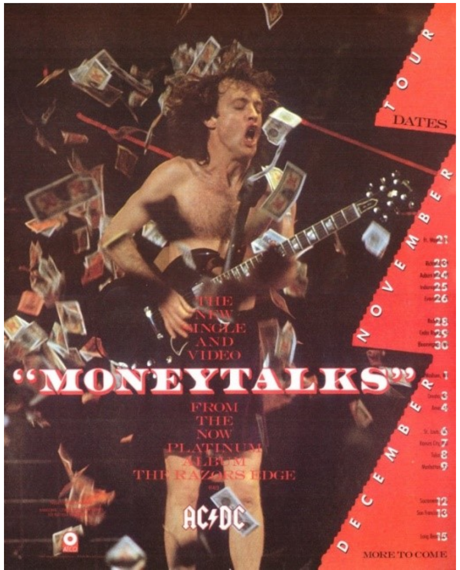
$$d = \frac{1}{4} \cdot 10cm = 2.5cm$$

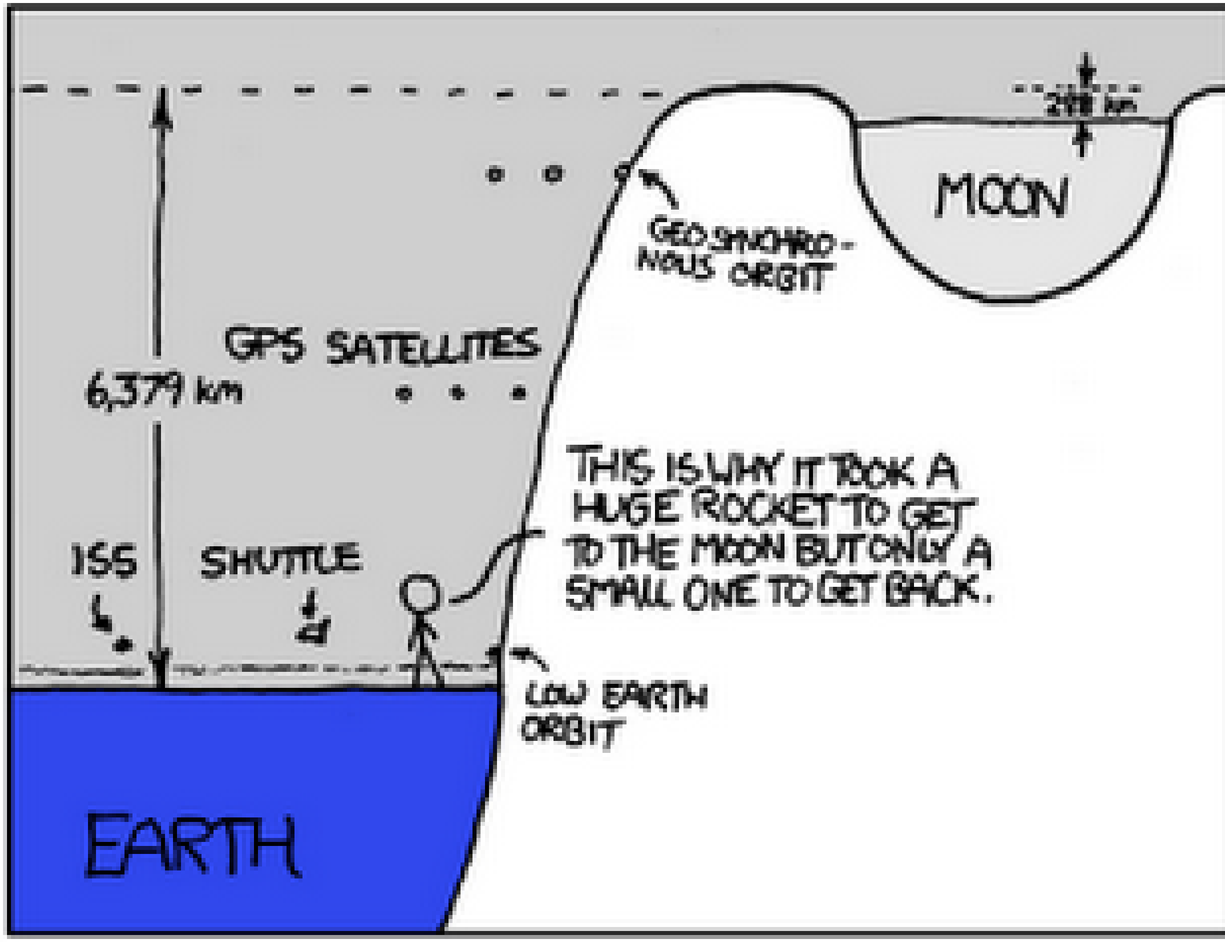
Exercises

- p. 162 #1, 2, 3a-c
- Careful, electrons fall <u>up</u>!

Potential Energy

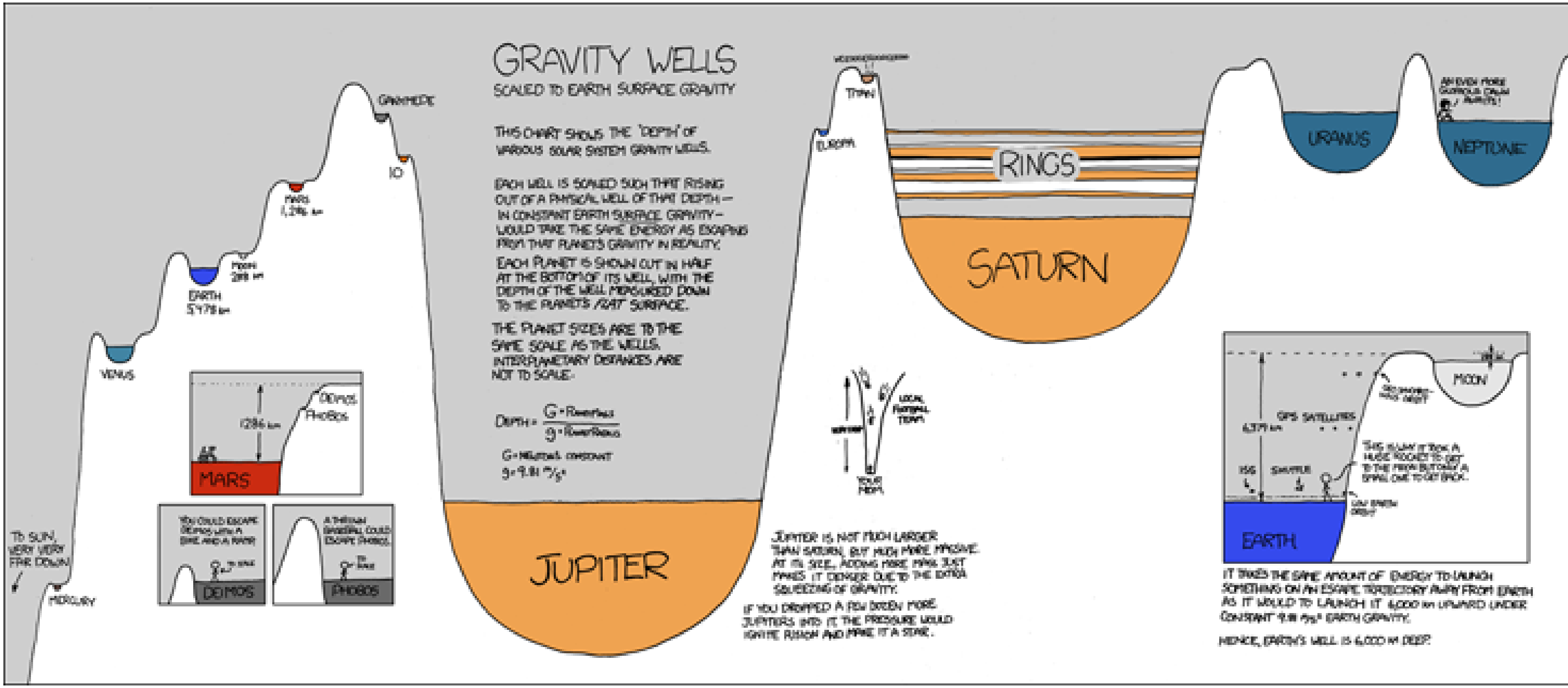
- Similar to gravitational potential energy we have electric potential energy
- The main difference is this can be positive or negative, depending on the charges
- ®Opposites: Owe; Like Charges: Dough! TM



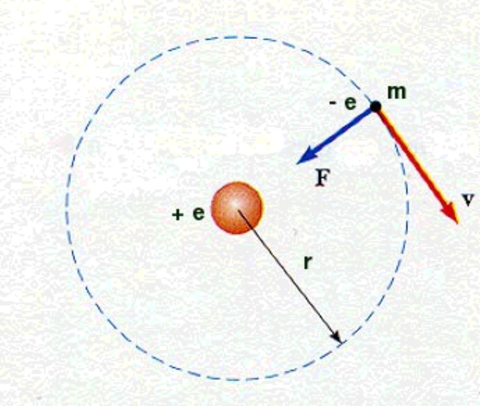


IT TAKES THE SAME AMOUNT OF ENERGY TO LAUNCH SOMETHING ON AN ESCAPE TRAJECTORY AWAY FROM EARTH AS IT WOULD TO LAUNCH IT 6,000 km UPWARD UNDER CONSTANT 9.81 m/s² EARTH GRAVITY.

HENCE, EARTH'S WELL IS 6,000 km DEEP.


GRAVITY WELLS
SCALED TO EARTH SURFACE GRAVITY
THIS CHART SHOWS THE "DEPTH" OF VARIOUS SOLAR SYSTEM GRAVITY WELLS.
EACH WELL IS SCALED SUCH THAT RISING OUT OF A PHYSICAL WELL OF THAT DEPTH — IN CONSTANT EARTH SURFACE GRAVITY — WOULD TAKE THE SAME ENERGY AS ESCAPING FROM THAT PLANET'S GRAVITY IN REALITY.
EACH PLANET IS SHOWN CUT IN HALF AT THE BOTTOM OF ITS WELL, WITH THE DEPTH OF THE WELL MEASURED DOWN TO THE PLANET'S FLAT SURFACE.
THE PLANET SIZES ARE TO THE SAME SCALE AS THE WELLS. INTERPLANETARY DISTANCES ARE NOT TO SCALE.
G = NEWTON'S CONSTANT
g = 9.81 m/s²
TO SUN, VERY VERY FAR DOWN
MERCURY
VENUS
EARTH
5,478 km
MARS
1,286 km
GANYMEDE
IO
MARS
DEIMOS
PHOBOS
1286 km
DEIMOS
PHOBOS
JUPITER
EUROPA
TITAN
RINGS
SATURN
URANUS
NEPTUNE
MOON
EARTH
ISS
SHUTTLE
GPS SATELLITES
JUPITER IS NOT MUCH LARGER THAN SATURN, BUT MUCH MORE MASSIVE. AT ITS SIZE, ADDING MORE MASS JUST MAKES IT DENSER DUE TO THE EXTRA SQUEEZING OF GRAVITY.
IF YOU DROPPED A FEW DOZEN MORE JUPITERS INTO IT, THE PRESSURE WOULD IGNITE FUSION AND MAKE IT A STAR.
IT TAKES THE SAME AMOUNT OF ENERGY TO LAUNCH SOMETHING ON AN ESCAPE TRAJECTORY AWAY FROM EARTH AS IT WOULD TO LAUNCH IT 6,000 km UPWARD UNDER CONSTANT 9.81 m/s² EARTH GRAVITY.
HENCE, EARTH'S WELL IS 6,000 km DEEP.

Ex 1:Find E_p



- What is the potential energy of an electron in a H atom?

$$E_p = \frac{kQq}{r}$$

$$E_p = \frac{9\times10^{9}\ Nm^2/C^2\left(-1.6\times10^{-19}C\right)\left(1.6\times10^{-19}C\right)}{\left(5\times10^{-11}m\right)}$$

$$E_p = -4.6\times10^{-18}J$$

Order of the universe in 12 steps

- 10^{25} m
- 10^{20}
- 10^{15}
- 10^{10}
- 10^{5}
- 10^{0}

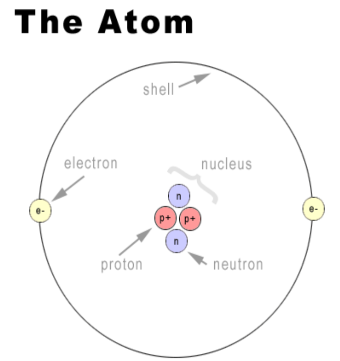
- Observable universe
- Milky Way
- Solar System
- Giant Star
- Small moon*
- Human

- *That's no moon, it's a space station!

Order of the universe

- 10^0 m
- 10^{-5}
- 10^{-10}
- 10^{-15}
- 10^{-20}
- 10^{-25}
- 10^{-30}
- 10^{-35}

- Human
- Bacterium
- Atom
- Nucleus
- Quark
- String?
- Quantum Gravity?
- Planck Length



Ex 2:Find E_p

- What is the electric potential energy of the protons in a He atom if they are 1fm apart?

$$E_p = \frac{kQq}{r}$$

$$E_p = \frac{9\times10^9\ Nm^2/C^2\,(1.6\times10^{-19}C)(1.6\times10^{-19}C)}{(10^{-15}m)}$$

$$E_p = 0.23pJ$$

Electric Potential

- This is analogous to field being force per unit charge
- Potential is the energy per unit charge (c.f. elevation)
- J/C≡Volts

$$V = \frac{kQ}{r}$$

Ex 3:Find V

- What is the electric potential midway between -2μC Cujo and 2μC Killer if they are 2m apart?
- Cujo:

$$V = \frac{kQ}{r}$$

$$V = \frac{9\times10^{9}\, Nm^2/C^2 \left(-2\times10^{-6}C\right)}{1m}$$

$$V = -18kV$$

Ex 3:Find V

- Killer:

$$V = \frac{kQ}{r}$$

$$V = \frac{9 \times 10^{9}\, Nm^{2}/C^{2} \left(2 \times 10^{-6} C\right)}{1m}$$

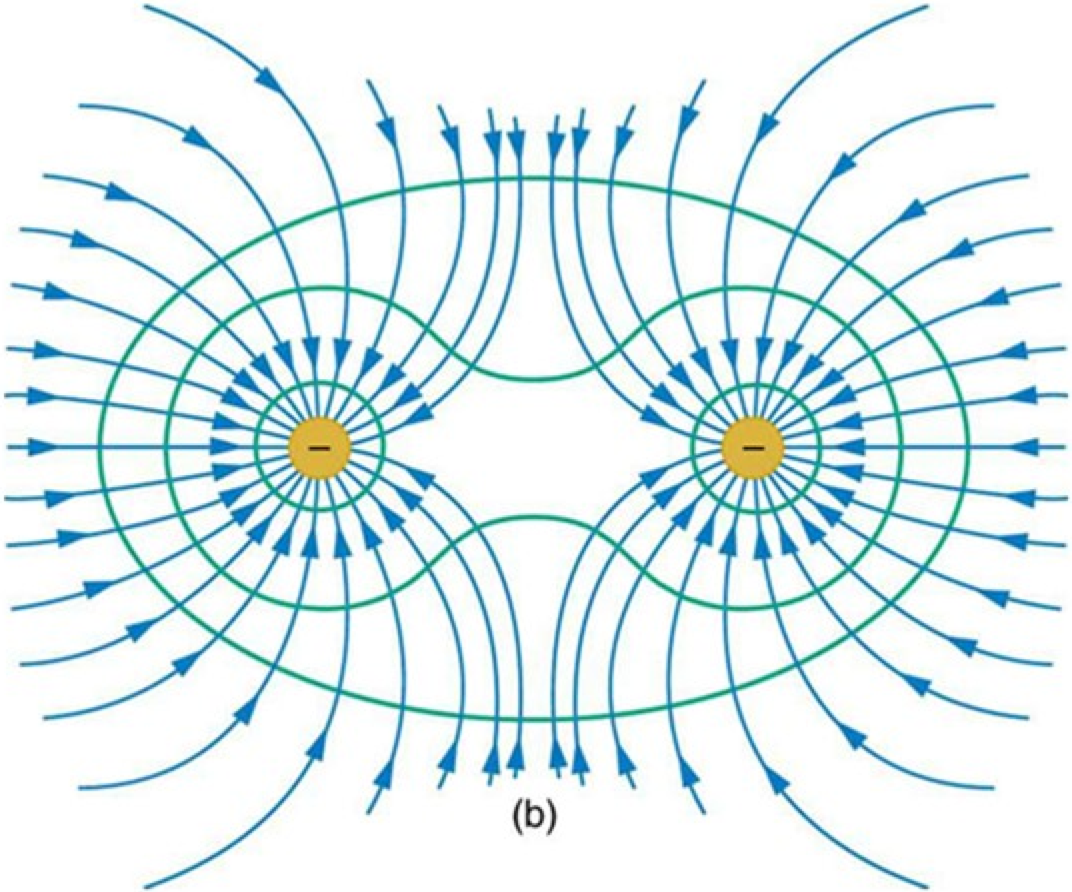
$$V = 18kV$$

- Overall:

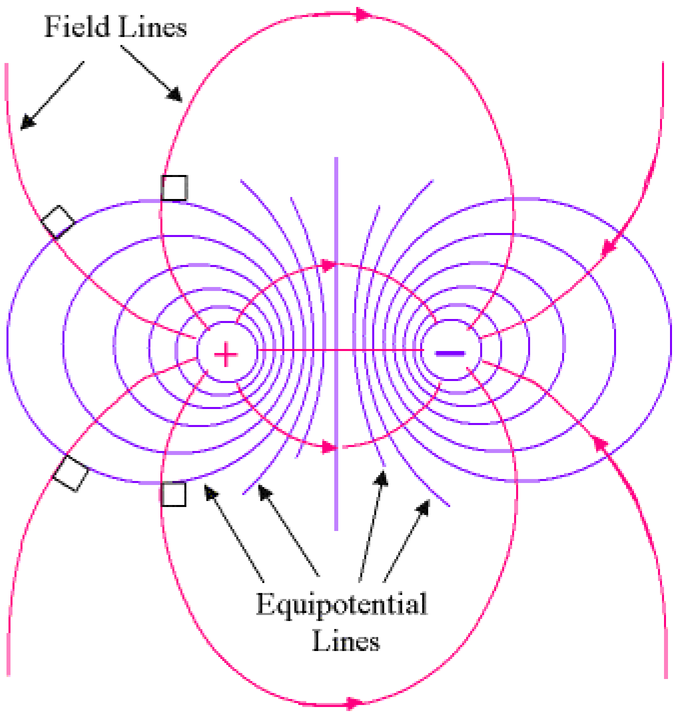
$$V = -18kV + 18kV = 0$$

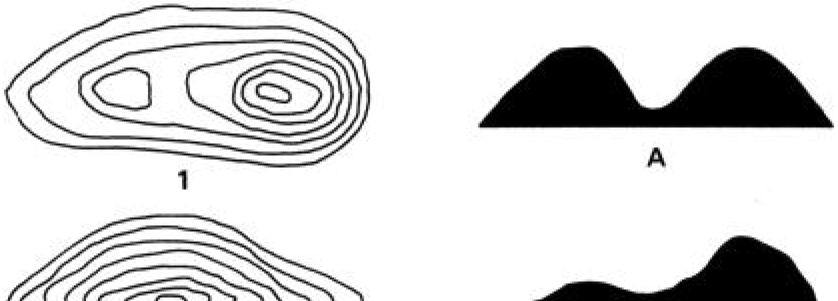
Equipotential lines

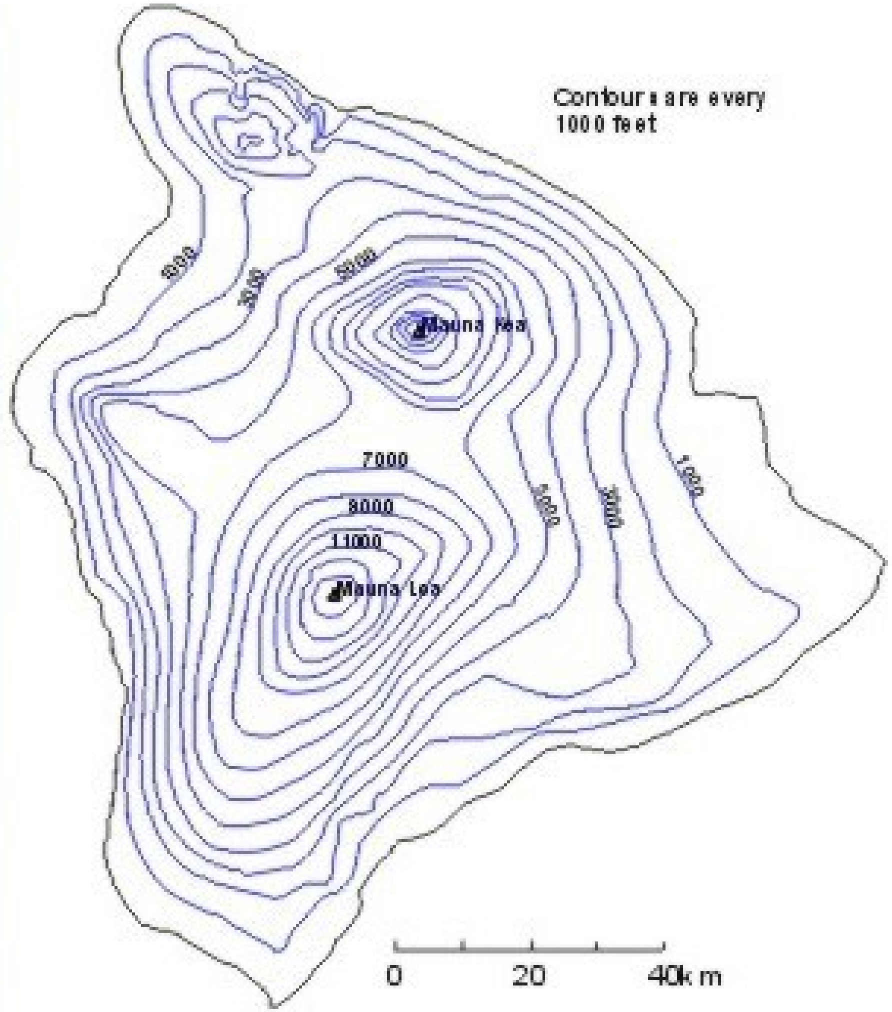
- Always perpendicular to field



(b)



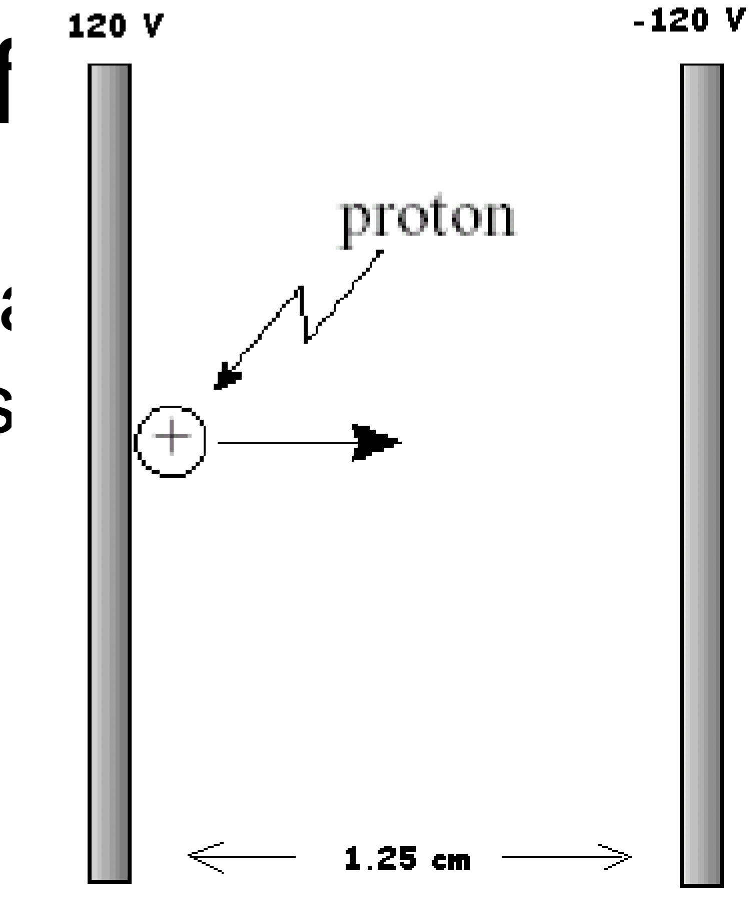

1
A


Contours are every
1000 feet
7000
8000
11000
0
20
40km

Potential Dif

- We can use the potenti
between two points to s
since:

$$W = q\Delta V_e$$



- Ex: what is the change in potential energy as the proton moves across this capacitor?

$$W = q\Delta V_e$$

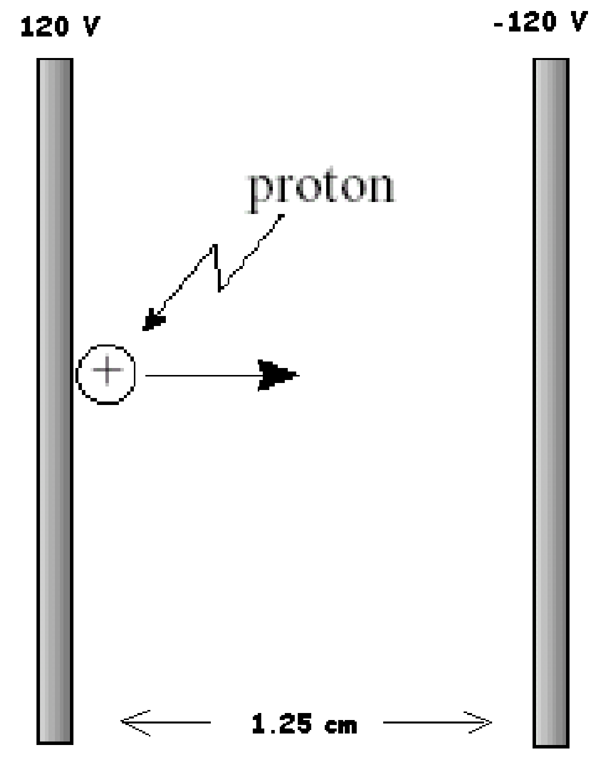
$$W = 1e \cdot -240V$$

- Sometimes use the unit of eV for energy

$$W = -240eV$$

$$1eV = 1.6 \times 10^{-19} J$$

$$W = -3.84 \times 10^{-17} J$$



Energy Conservation

- If the proton has lost potential energy travelling from one plate to the other:

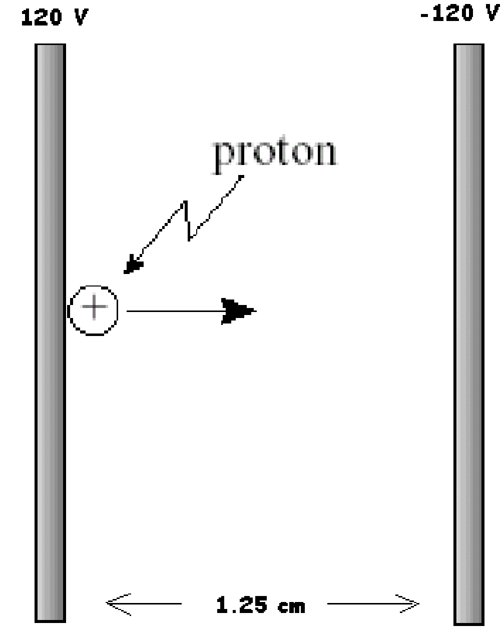
  $\Delta E=0$

  then it has gained kinetic energy
- What is the maximum speed of the proton?

$$\Delta E = 0$$

$$\Delta E_k = -\Delta E_p$$

$$\Delta E_k = 3.84 \times 10^{-17} J$$



$$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \cdot 3.84 \times 10^{-17} J}{1.67 \times 10^{-27} kg}}$$

$$v = 214 \, {}^{km}\!/_{s}$$

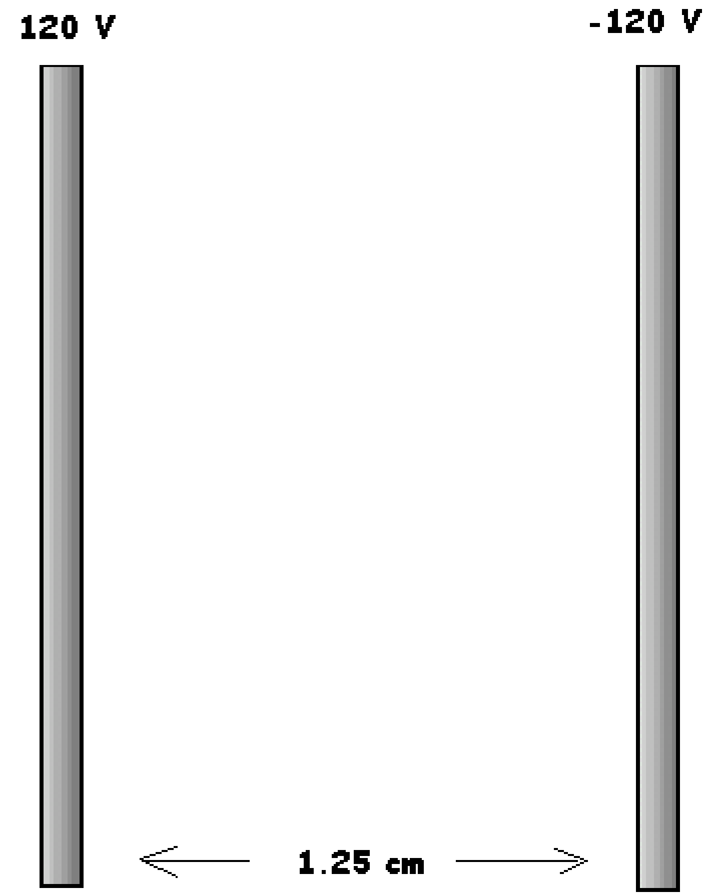
Exercises

- p. 166 #1-5
- What are you doing Friday? Quiz? What's up with that?
- Chapter Review p. 166-8

More Capa

- We can also find the ele
potential difference sinc

$$E = -\frac{\Delta V_e}{\Delta r}$$

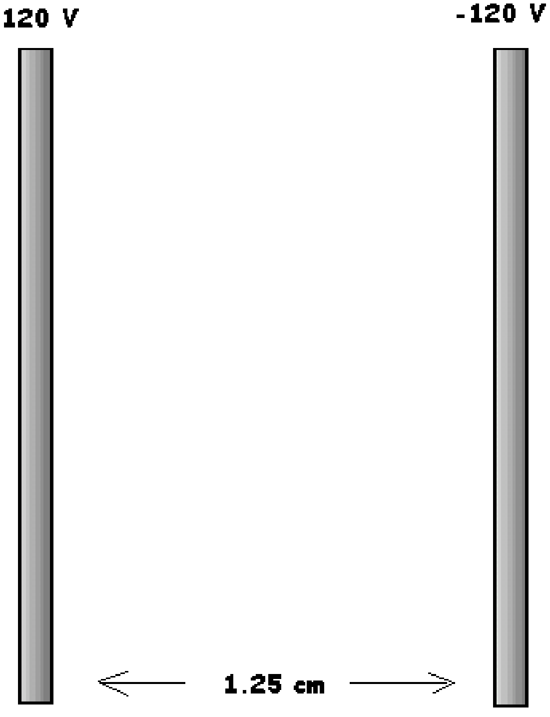


- Ex: what is the magnitude and direction of the electric field in this capacitor?

$$E = -\frac{\Delta V_e}{\Delta r}$$

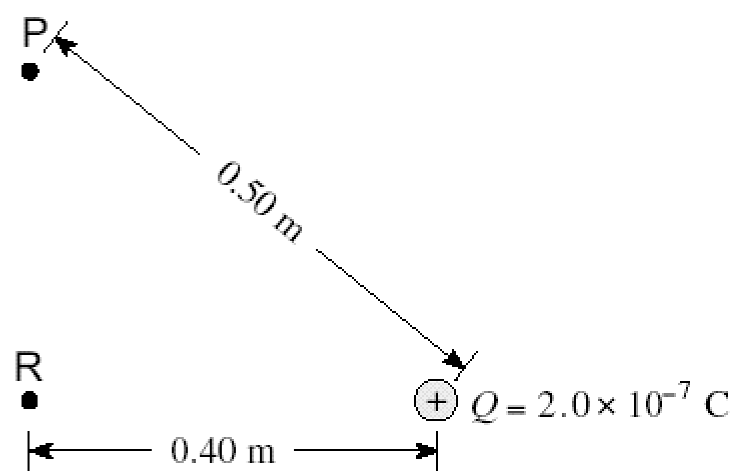
$$E = \frac{240V}{0.0125m}$$

$$E = 19.2\,{}^{kN}\!/_{C} \rightarrow right$$

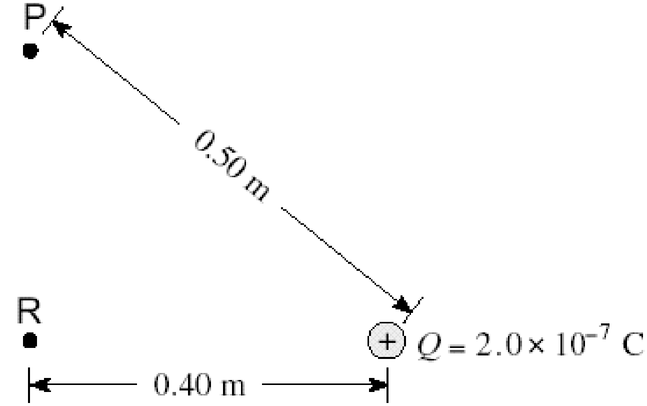


More Potential Difference

- Ex: What is the electric potential difference between points P and R due to the fixed point
- charge *Q*?



$$V_P = \frac{kQ}{r_P}$$



$$V_P = \frac{9\times10^{9}\ Nm^2/C^2 \cdot 2.0\times10^{-7}\,C}{0.50m}$$

$$V_P = 3600V$$

$$V_R = \frac{kQ}{r_R}$$

$$V_R = \frac{9\times10^{9}\ Nm^2/C^2 \cdot 2.0\times10^{-7}\,C}{0.40m}$$

$$V_R = 4500V \quad \Delta V = V_R - V_P = 900V$$

Work done

- How much work is done in moving a charged particle?

Work done

$=q\Delta V$ for a known potential difference

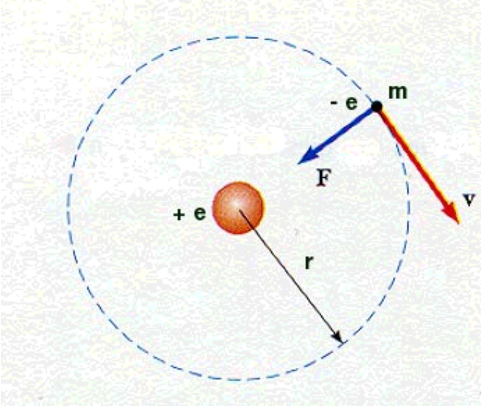
$= \Delta E_p$ for point charges

*Don't use W=Fd! F is usually not constant!!

Exception? W=qEd for a **uniform** electric field

Ex: how much work is done in ionizing a H atom?

- Work done is change in potential energy

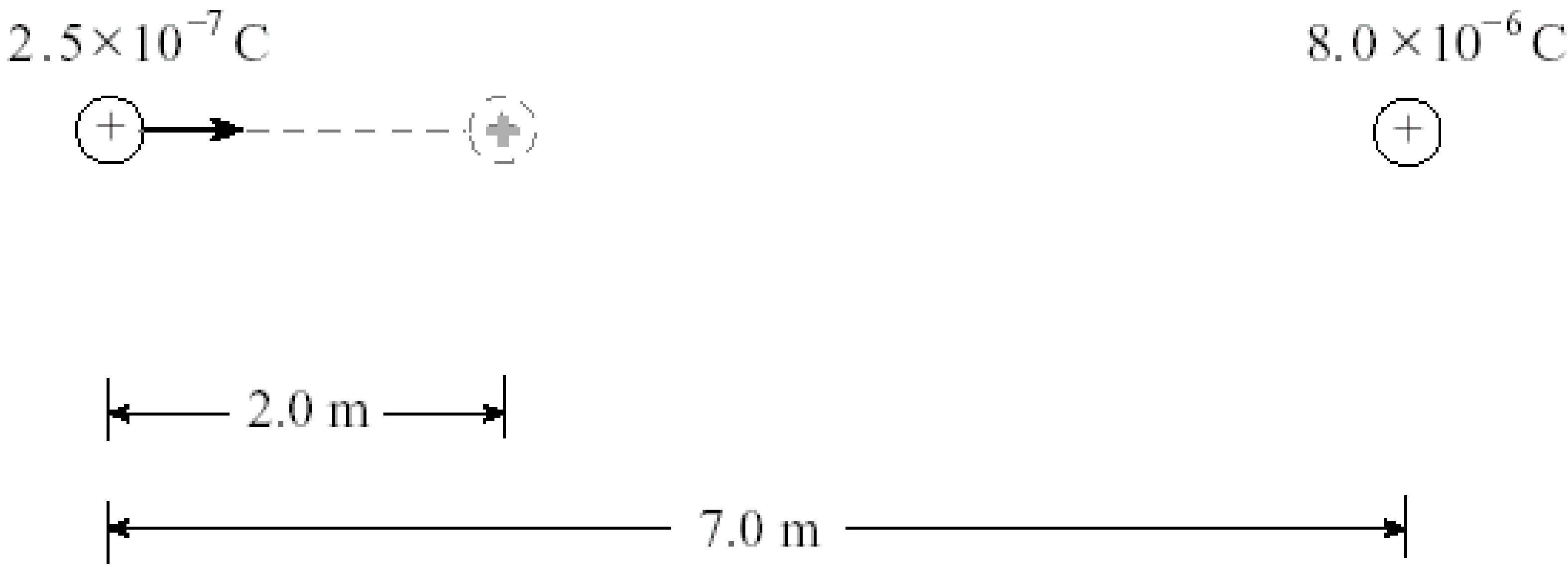


$$W = \Delta E_p = kQq\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

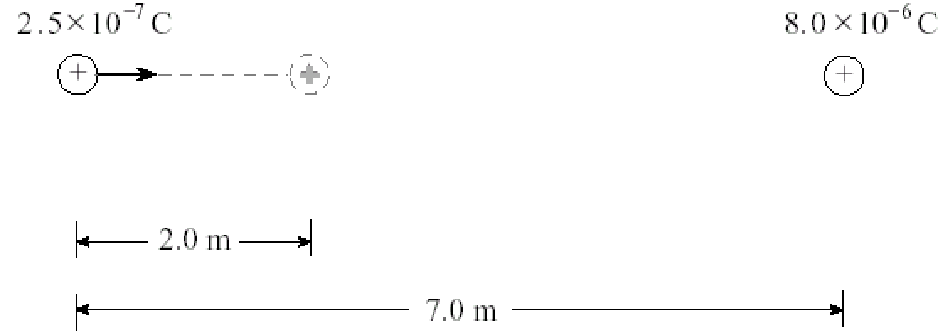
$$W = 9\times10^9\ Nm^2/C^2\left(-1.6\times10^{-19}C\right)1.6\times10^{-19}C\left(\frac{1}{\infty} - \frac{1}{\left(5\times10^{-11}m\right)}\right)$$

$$W = 4.6\times10^{-18}J$$

Ex 2: find the work done on the .25 μC charge



$$W = Fd?$$



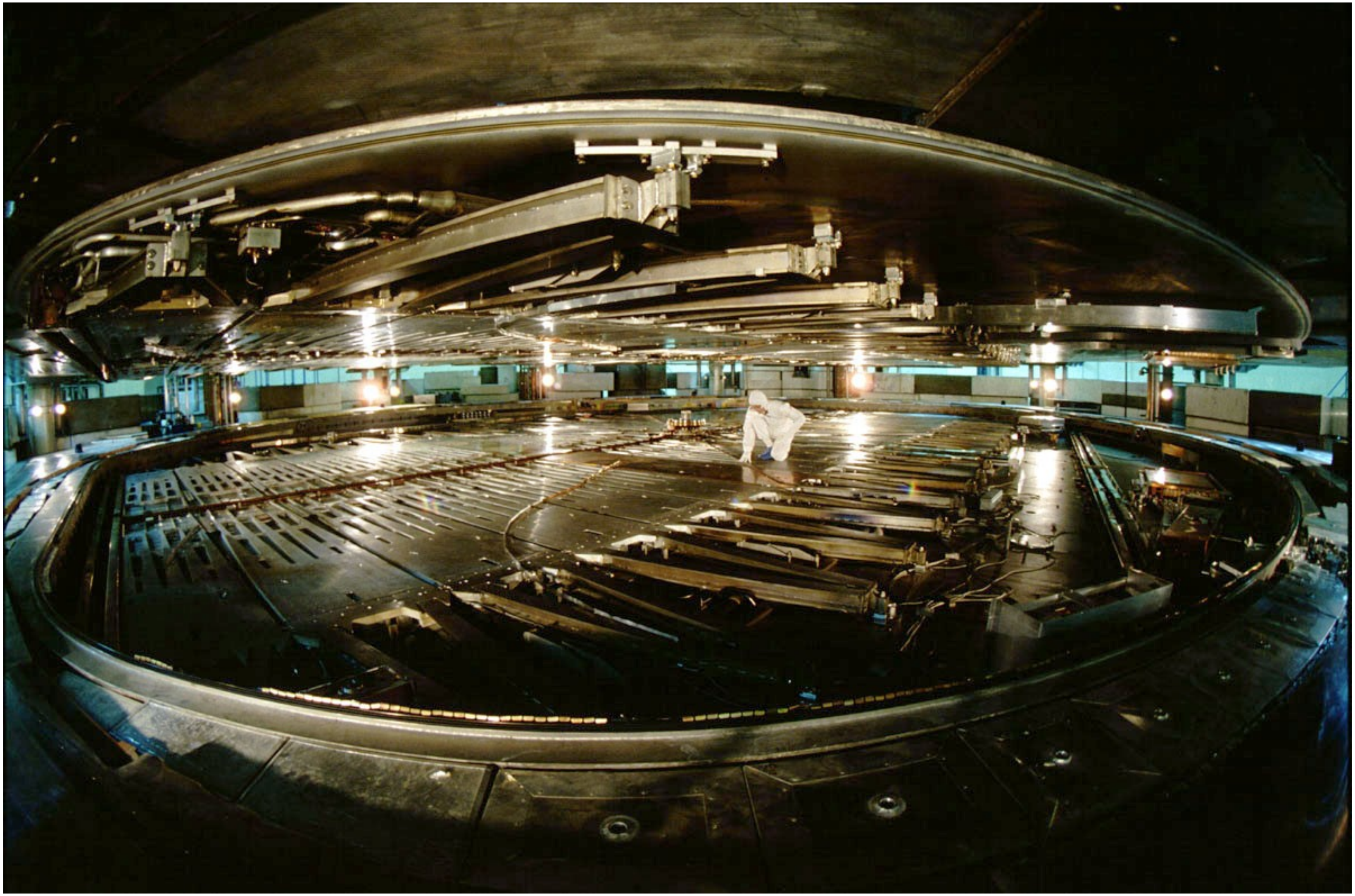
$$W = \Delta E_p$$

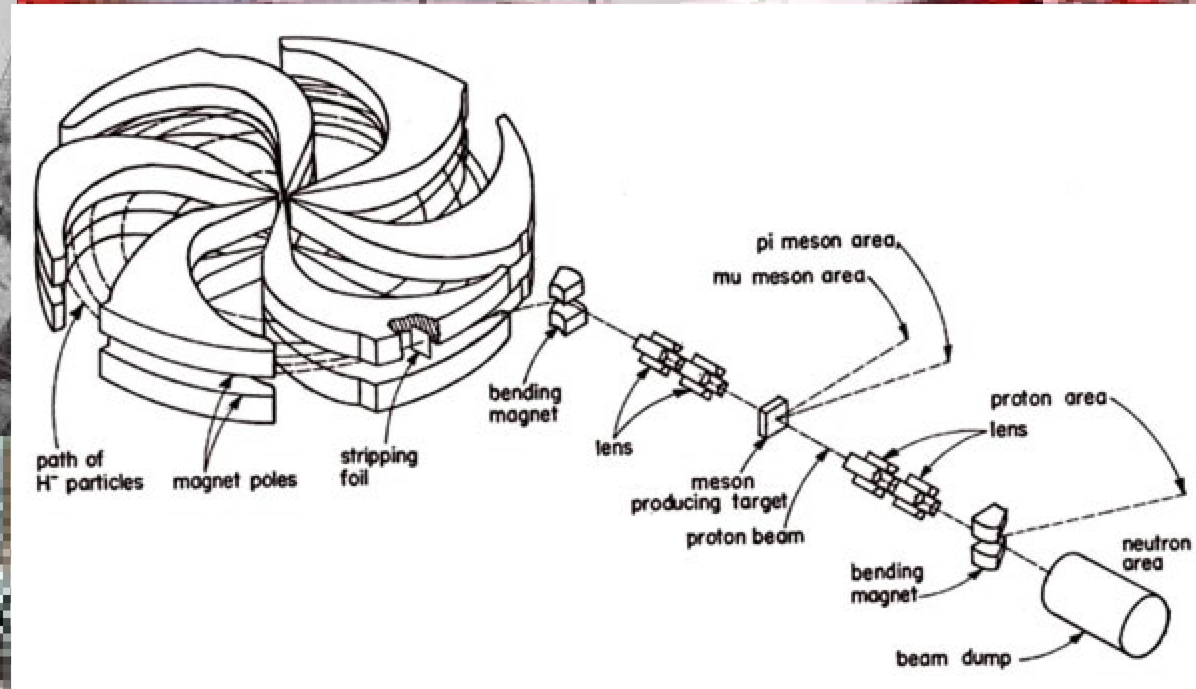
$$W = kQq\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

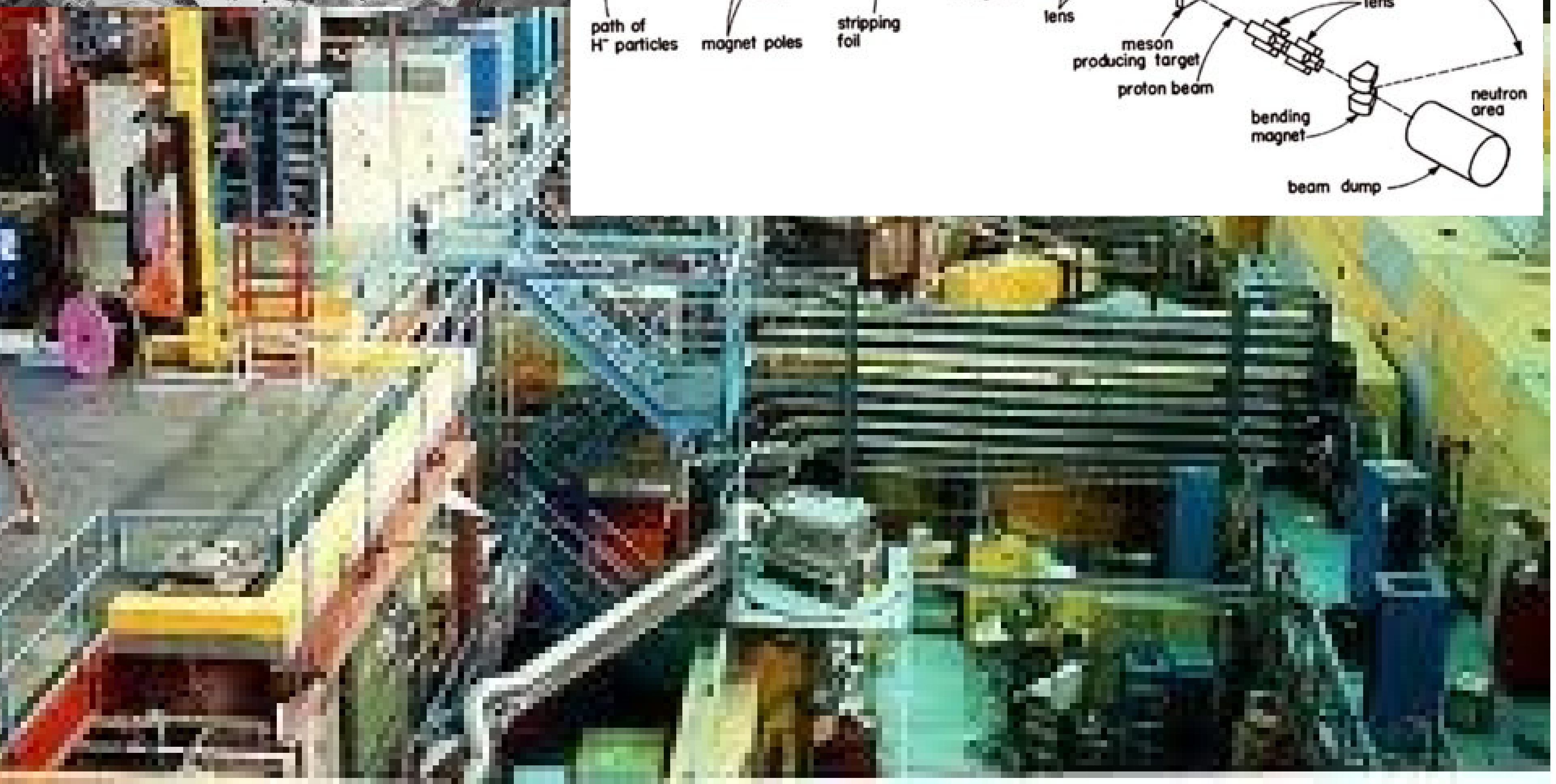
$$W = 9\times10^{9}\ Nm^2/C^2\,(2.5\times10^{-7}\,C)(8.0\times10^{-6}\,C)\left(\frac{1}{5m} - \frac{1}{7m}\right)$$

$$W = 1.03\times10^{-3}\,J$$

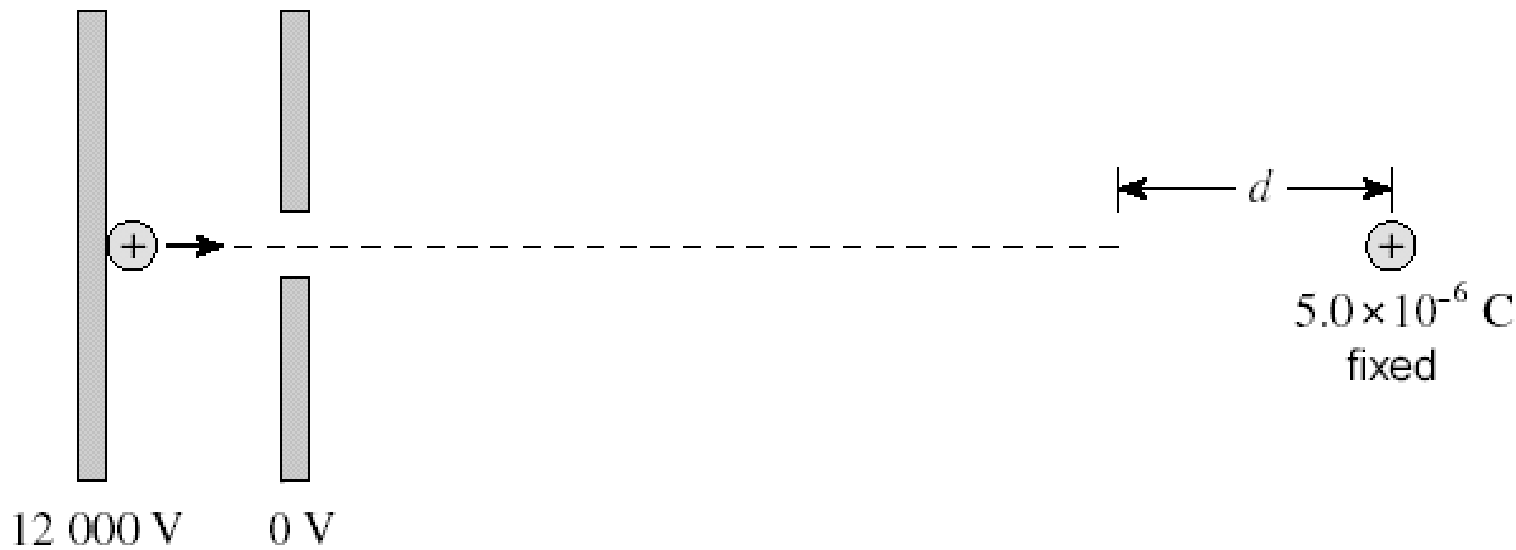
Proton Gun?!




pi meson area
mu meson area
bending magnet
lens
meson producing target
proton beam
proton area
lens
neutron area
bending magnet
beam dump
path of H⁻ particles
magnet poles
stripping foil



A proton, accelerated from rest through a potential difference of 1.2×10^4 V, is directed at a fixed 5.0×10^{-6} C charge.



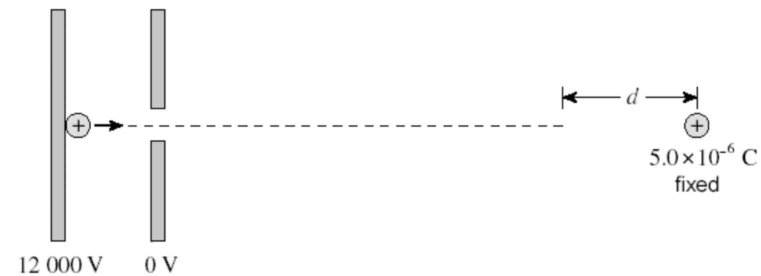
(Diagram not to scale.)

a) What is the speed of the proton as it leaves the parallel plates? **(4 marks)**

$$\Delta E_P = q\Delta V \quad \Delta E_k = -\Delta E_P$$

$$\Delta E_k = -q\Delta V = -\left(1.6\times10^{-19}\,C\right)\left(-12000\,V\right)$$

A proton, accelerated from rest through a potential difference of 1.2×10^4 V, is directed at a fixed 5.0×10^{-6} C charge.



(Diagram not to scale.)

a) What is the speed of the proton as it leaves the parallel plates? **(4 marks)**

$$\Delta E_k = 1.92\times10^{-15}\,J$$

$$v=\sqrt{\frac{2E_k}{m}}$$

$$v=\sqrt{\frac{2\cdot1.92\times10^{-15}\,J}{1.67\times10^{-27}\,kg}}$$

$$v=1.52\times10^{6}\,{}^{m}\!/_{s}$$

b) What is the distance *d* from the fixed charge when the proton is stopped?

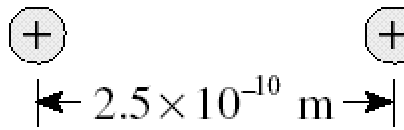
$$W = kQq\left(\frac{1}{r_2} - \frac{1}{r_1}\right) = kQq\left(\frac{1}{r_2} - 0\right)$$

$$W = \frac{kQq}{r_2} \quad r_2 = \frac{kQq}{E_k}$$

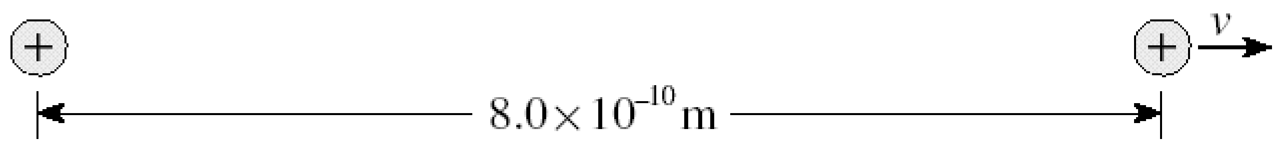
$$r_2 = \frac{9\times10^9\,Nm^2C^{-2}\cdot1.6\times10^{-19}\,C\cdot5.0\times10^{-6}\,C}{1.92\times10^{-15}\,J}$$

$$r_2 = 3.75m$$

Two protons are initially held at rest 2.5×10^{-10} m apart.



If one of the protons is released as shown below, what is its speed when it is 8.0×10^{-10} m from the fixed proton? **(7 marks)**



fixed proton

$$W = \Delta E_p$$

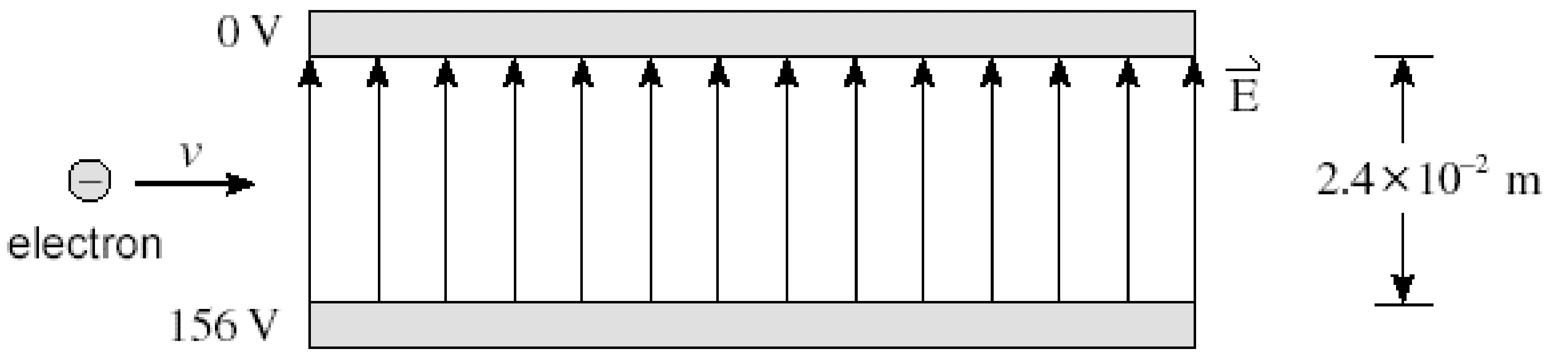
$$W = kQq\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

$$W = 9\times10^{9}\ Nm^2/C^2\left(1.6\times10^{-19}C\right)1.6\times10^{-19}C\left(\frac{1}{8.0\times10^{-10}m}-\frac{1}{2.5\times10^{-10}m}\right)$$

$$\Delta E_k = -\Delta E_p$$

$$v=\sqrt{\frac{2E_k}{m}} \qquad v=\sqrt{\frac{2\cdot 6.34\times10^{-19}J}{1.67\times10^{-27}kg}}$$

$$v = 2.75\times10^{4}\ m/s$$

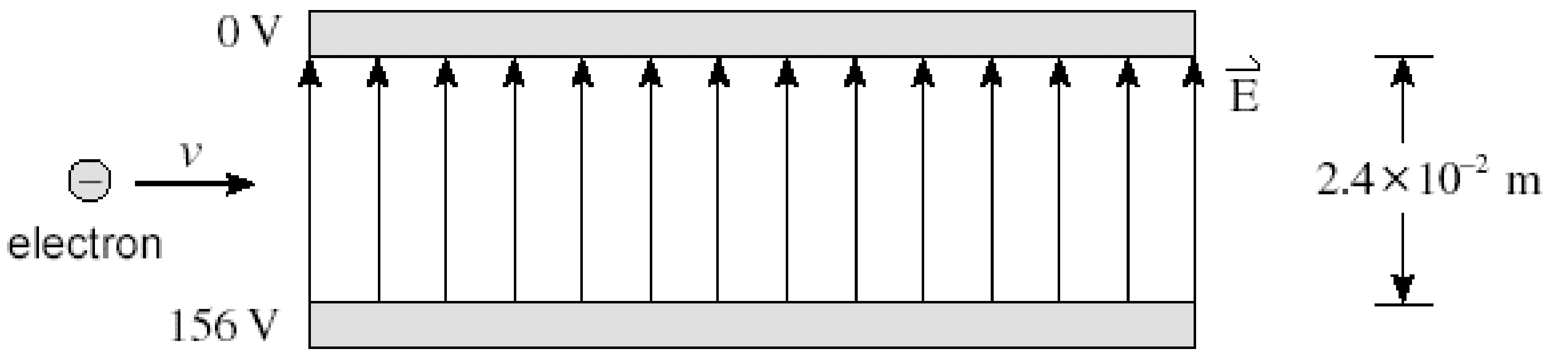


What are the magnitude and direction of the electrostatic force on the electron while it is between the plates? **(5 marks)**

$$F = qE$$

$$F = qE = \frac{q\Delta V}{d}$$

$$F = \frac{-1.6\times10^{-19}C \cdot 156V}{0.024m}$$



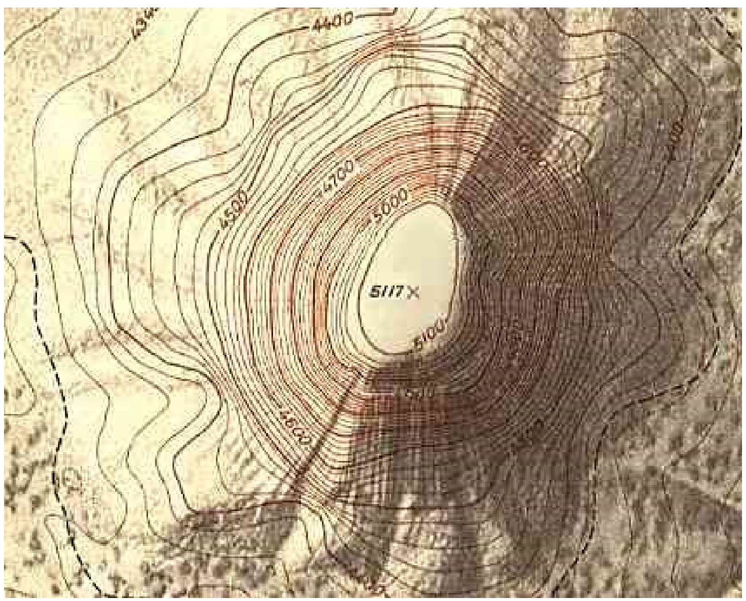
What are the magnitude and direction of the electrostatic force on the electron while it is between the plates? **(5 marks)**

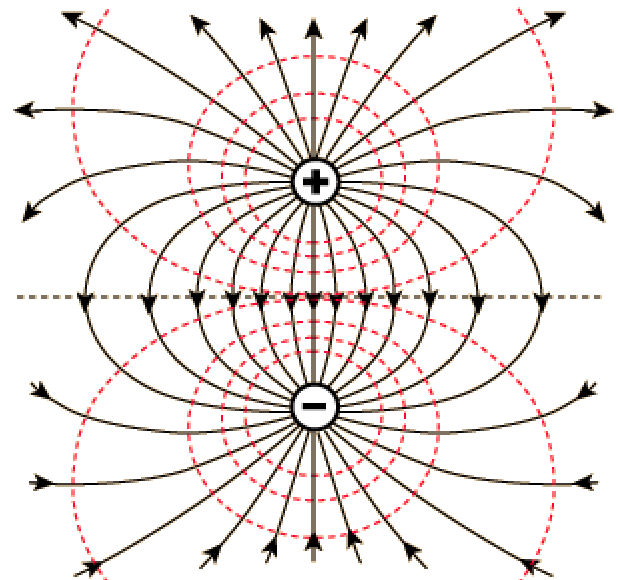
$$F = -1.04 \times 10^{-15}\,N$$

- The negative reminds us that for a negative charge, force is in the opposite direction as field
- $\therefore$ Force is downward

Equipotential lines

- Similar to a contour map
- Shows areas of equal potential
- Always perpendicular to field lines





LIVEWIRE

Leslie Willis was the rudest radio star in Metropolis, filling her broadcasts with rants against Superman. But the Man of Steel gave her the jolt of her life! As a thunderstorm raged at a concert promoting her radio show, a bolt o lightning passed through Superman's body and turned Leslie into Livewire, a being of pure electrical energy!

HIGH-VOLTAGE VILLAIN

Livewire is composed entirely of living electricity. She can control electric power in all its forms, making her a high-powered villain who can zap Superman silly!

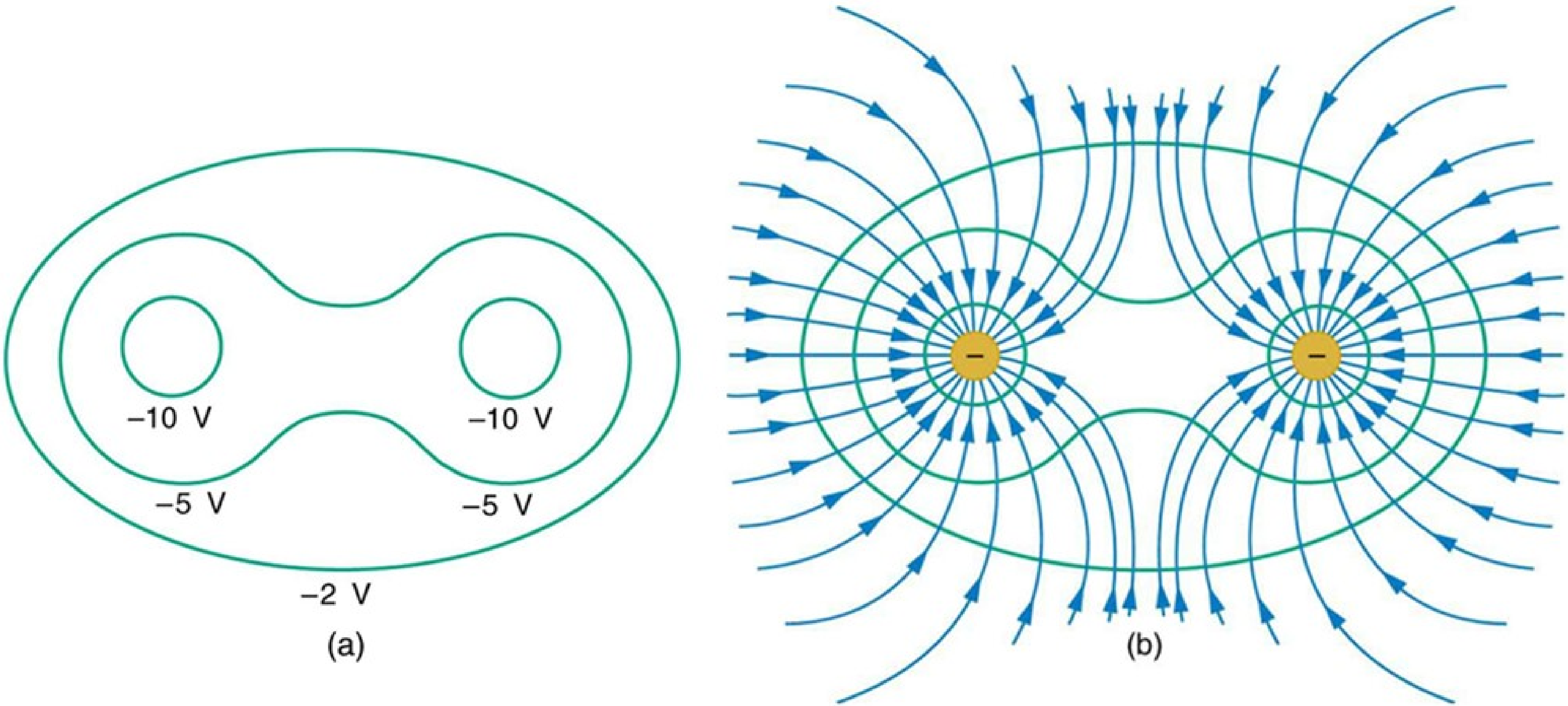
SUDDEN APPEARANCES are easy

BRAINIAC

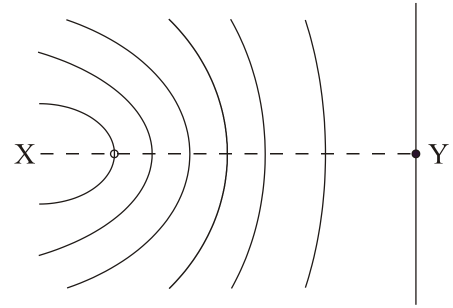
Livewire caused a shock when she saved the world! When Brainiac was about to press a button that would detonate every atomic bomb on Earth, Livewire used her powers to short-circuit the nuclear nightmare!

SUP

- Livew each u
- Livew rogues Quinn Batgirl up her

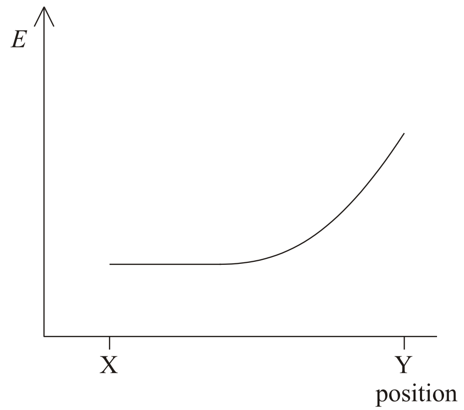

−10 V
−10 V
−5 V
−5 V
−2 V
(a)
−
−
(b)

1. The diagram below shows some lines of equipotential in the region of an electric field.

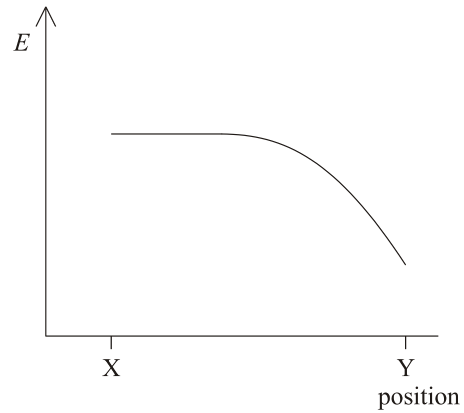


Which graph best shows the magnitude *E* of the electric field strength along the line XY?

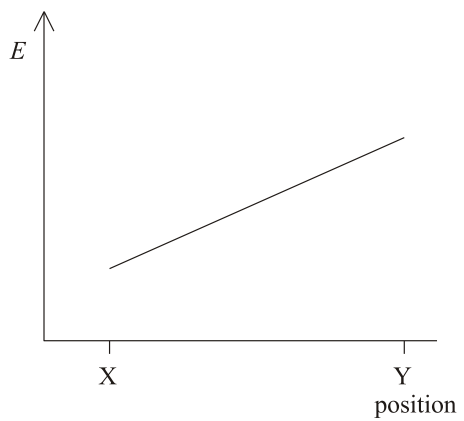
A.



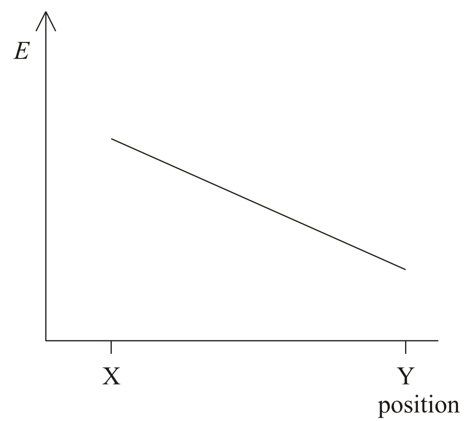
B.



C.



D.



Review

- V=potential
- Ep=potential energy
- F=force
- Q=charge
- r=radial distance
- Delta=change in…

Review

- Chapter Review Questions p. 166-168 1-15 (Bonus 16-18)
- Test Yourself p. 169-172 1-17
- Chapter 5 test Thursday?!