EF03 ELECTRIC POTENTIAL

SPH4U

CH 7 – KEY IDEAS

- define and describe concepts and units related to electric and gravitational fields
- state Coulomb's law and Newton's law of universal gravitation, and analyze, compare, and apply them in specific contexts
- compare the properties of electric and gravitational fields by describing and illustrating the source and direction of the field in each case
- apply quantitatively the concept of electric potential energy and compare it to gravitational potential energy
- analyze quantitatively, and with diagrams, electric fields and electric forces in a variety of situations
- describe and explain the electric field inside and on the surface of a charged conductor and how the properties of electric fields can be used to control the electric field around a conductor
- perform experiments or simulations involving charged objects
- explain how the concept of a field developed into a general scientific model, and describe how it affected scientific thinking

EQUATIONS

- Electrical Potential Energy

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

- Electric Potential

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

- Electric Potential Difference

$$\Delta V = \frac{\Delta E_E}{q} = kq\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$$

- Electric Field

$$\varepsilon = \frac{\Delta V}{r}$$

RECALL: GRAVITATIONAL POTENTIAL ENERGY

- Gravitational Force

$$F_g = \frac{GMm}{r^2}$$

- Gravitational Potential Energy

$$E_g = \frac{GMm}{r}$$

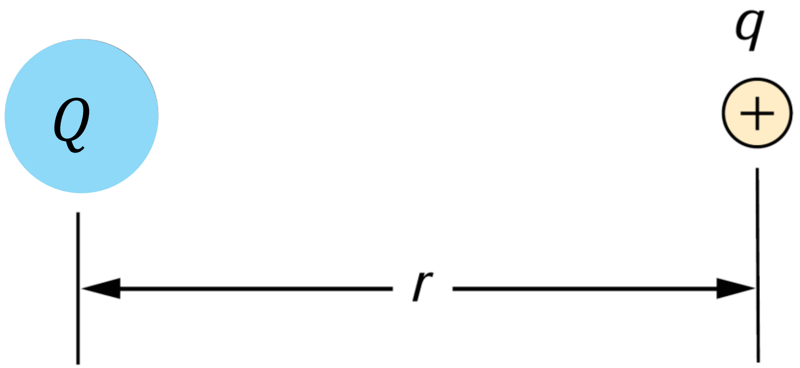
ELECTRICAL POTENTIAL ENERGY

- Since electrical force follows the same pattern as gravitational force, it follows that electrical energy would follow a similar pattern

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

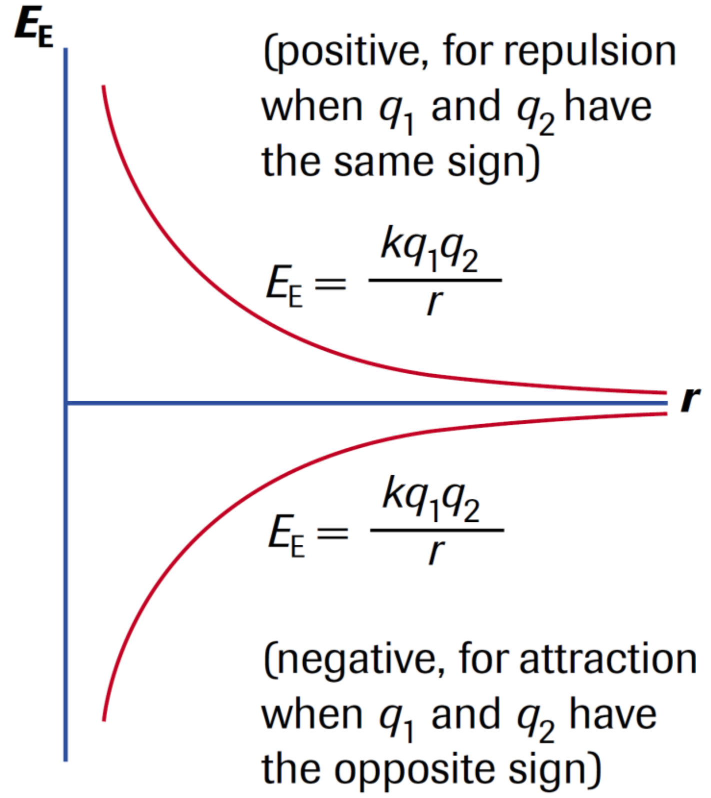
- **Electric Potential Energy (E_E) [J]:** the energy stored in a system of two charges a distance r apart

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



ELECTRICAL POTENTIAL ENERGY – CONT.

- Similar to gravitational potential energy, the magnitude approaches zero as the distance between particles approaches infinity
- This relationship holds for two like charges (positive E_E) and for two different charges (negative E_E)



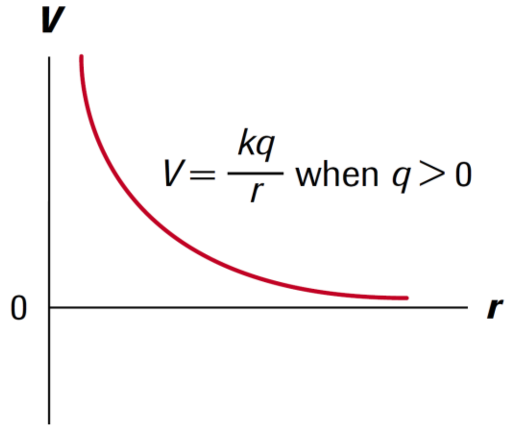
ELECTRIC POTENTIAL

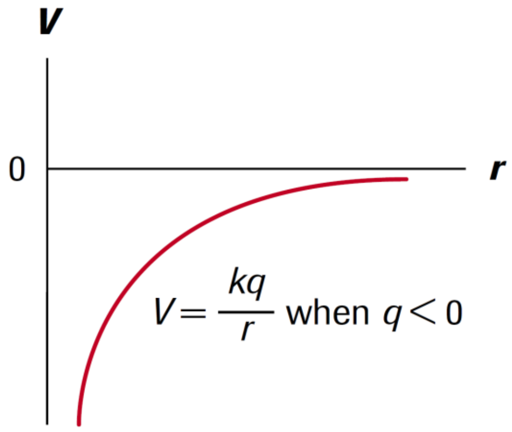
- **Electric Potential (V) [V = J/C]:** the value, in volts, of potential energy per unit positive charge
- 1V is the electric potential at a point in an electric field if 1 J of work is required to move 1 C of charge from infinity to that point.

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

  - E_E – electrical energy for a point charge [J]
  - q – magnitude of a test charge [C]
- For a point charge, Q,

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





ELECTRIC POTENTIAL DIFFERENCE

- **Electrical Potential Energy:** in terms of electrical potential

$$E_E = qV$$

- **Electric Potential Difference ($\Delta \boldsymbol{V}$):** the amount of work required per unit charge to move a positive charge from one point to another in the presence of an electric field

$$\mathrm{W} = \Delta E_E = E_{E,B} - E_{E,A}$$

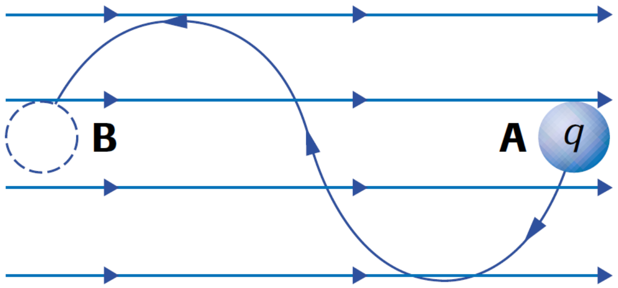
$$\Delta E_E = qV_B - qV_A$$

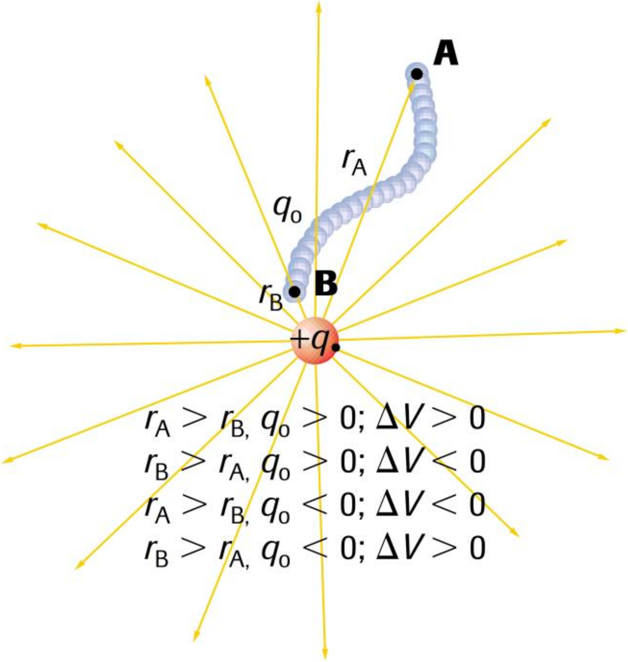
$$\Delta E_E = q\Delta V$$

ELECTRIC POTENTIAL DIFFERENCE – CONT.

- Electric potential difference is independent of the path taken
- For a point charge, Q, between A and B

$$\Delta V = V_B - V_A$$
$$\Delta V = \frac{kQ}{r_B} - \frac{kQ}{r_A}$$
$$\Delta V = kQ\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$$





ELECTRIC POTENTIAL DIFFERENCE – CONT.

- Recall: $\vec{\varepsilon} = \frac{\vec{F}_E}{q}$, per unit area (constant)
- For parallel plates
  - Work is done to increase potential energy from B to A, over a distance r, by a force $\vec{F} = -\vec{F}_E$

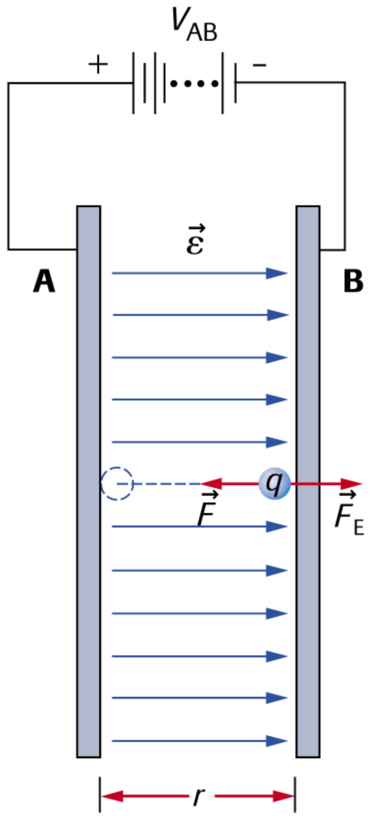
$$W = Fr = q\varepsilon r$$

    - (F and r are in the same direction)
  - Since $W = \Delta E_E = q\Delta V$

$$q\Delta V = q\varepsilon r$$

- For a constant electric field

$$\boldsymbol{\Delta V = \varepsilon r}$$



PROBLEM 1

Calculate the electric potential a distance of 0.40 m from a spherical point charge of $+6.4 \times 10^{-6}$ C. (Take $V = 0$ at infinity.)

PROBLEM 1 – SOLUTIONS

$r = 0.40 \text{ m}$

$q = +6.4 \times 10^{-6} \text{ C}$

$V = ?$

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

$$= \frac{(9.0 \times 10^{9} \text{ N}\cdot\text{m}^2/\text{C}^2)(6.4 \times 10^{-6} \text{ C})}{0.40 \text{ m}}$$

$$V = 1.5 \times 10^{5} \text{ V}$$

The electric potential is 1.5×10^{5} V.

PROBLEM 2

How much work must be done to increase the potential of a charge of 3.0×10^{-7} C by 120 V?

PROBLEM 2 – SOLUTIONS

$q = 3.0 \times 10^{-7}$ C

$\Delta V = 120$ V

$W = ?$

$$\begin{aligned} W &= \Delta E_E \\ &= q\Delta V \\ &= (3.0 \times 10^{-7}\ \text{C})(120\ \text{V}) \\ W &= 3.6 \times 10^{-5}\ \text{J} \end{aligned}$$

The amount of work that must be done is 3.6×10^{-5} J.

PROBLEM 3

In a uniform electric field, the potential difference between two points 12.0 cm apart is 1.50×10^2 V. Calculate the magnitude of the electric field strength.

PROBLEM 3 – SOLUTIONS

$r = 12.0 \text{ cm}$

$\Delta V = 1.50 \times 10^2 \text{ V}$

$\varepsilon = ?$

$$\varepsilon = \frac{\Delta V}{r}$$

$$= \frac{1.50 \times 10^2 \text{ V}}{1.20 \text{ x } 10^{-1} \text{ m}}$$

$$\varepsilon = 1.25 \times 10^3 \text{ N/C}$$

The magnitude of the electric field strength is 1.25×10^3 N/C.

PROBLEM 4

The magnitude of the electric field strength between two parallel plates is 450 N/C. The plates are connected to a battery with an electric potential difference of 95 V. What is the plate separation?

PROBLEM 4 – SOLUTIONS

$\varepsilon = 450 \text{ N/C}$

$\Delta V = 95 \text{ V}$

$r = ?$

For parallel plates, $\varepsilon = \dfrac{\Delta V}{r}$. Thus,

$$r = \frac{\Delta V}{\varepsilon}$$

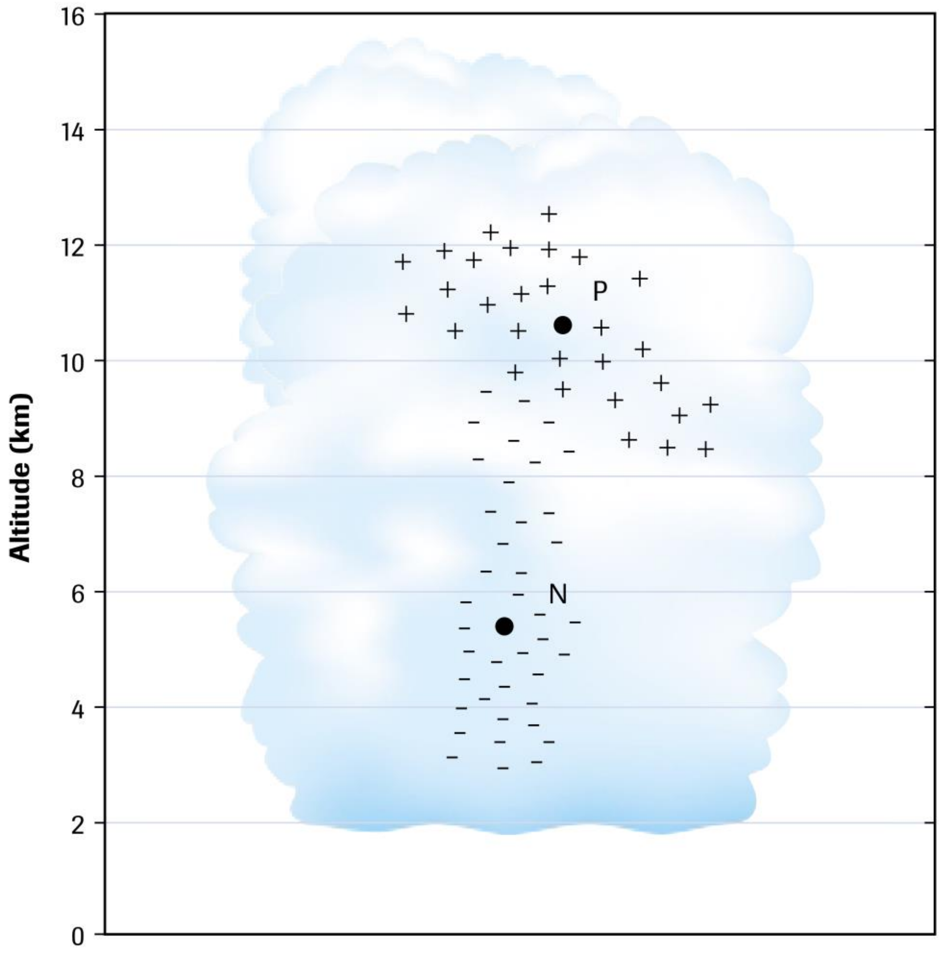
$$= \frac{95 \text{ V}}{450 \text{ N/C}}$$

$$r = 0.21 \text{ m}$$

The separation of the plates is 0.21 m.

LIGHTNING

- Through friction in the air, charges separate in thunderclouds
- Charge packets make their way to the surface, leaving a charged trail
- Packets induce a positive charge on the ground
- Upon contact, an ionized path is connected with the ground, sending a stroke of charge up the path
  - This creates light and sound



LIGHTNING RODS

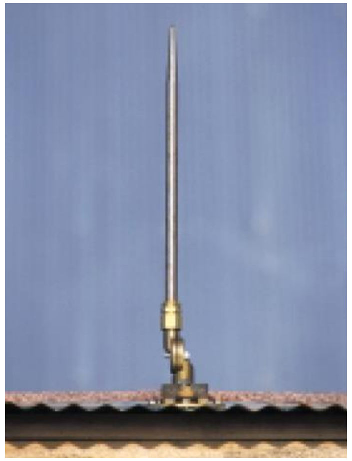
- How do lightning rods work?
- Consider to conducting spheres or different radii connected by a long wire
  - Connected = same potential (V)

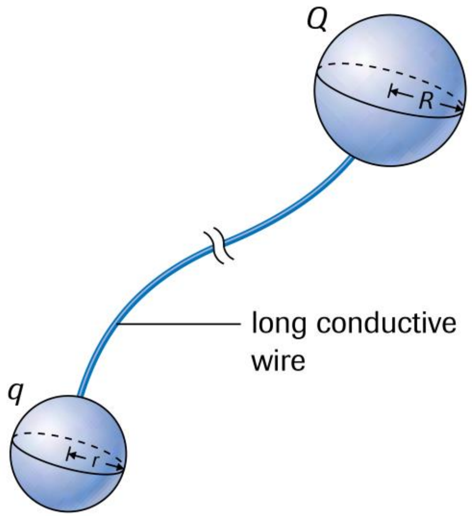
$$V_{small} = V_{large}$$

$$\frac{kq}{r} = \frac{kQ}{R}$$

$$\frac{q}{r} = \frac{Q}{R}$$

$$\frac{q}{Q} = \frac{r}{R}$$





LIGHTNING RODS – CONT.

- The electric fields of the spheres is given by

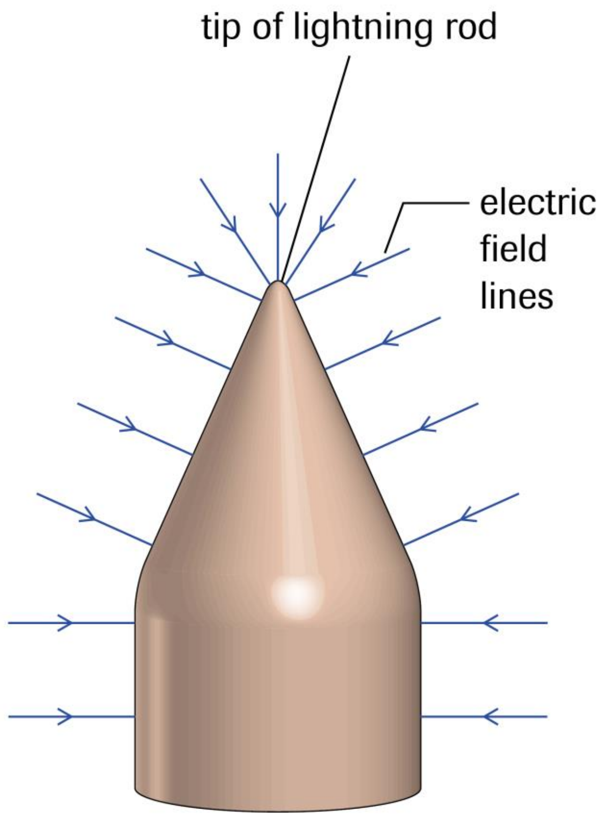
$$\varepsilon_{small} = \frac{kq}{r^2} \qquad \varepsilon_{large} = \frac{kQ}{R^2}$$

$$\frac{\varepsilon_{small}}{\varepsilon_{large}} = \frac{\left(\frac{kq}{r^2}\right)}{\left(\frac{kQ}{R^2}\right)} = \frac{q}{Q}\left(\frac{R^2}{r^2}\right) = \frac{r}{R}\left(\frac{R^2}{r^2}\right) = \frac{R}{r}$$

- Since $R > r$, $\varepsilon_{small} > \varepsilon_{large}$

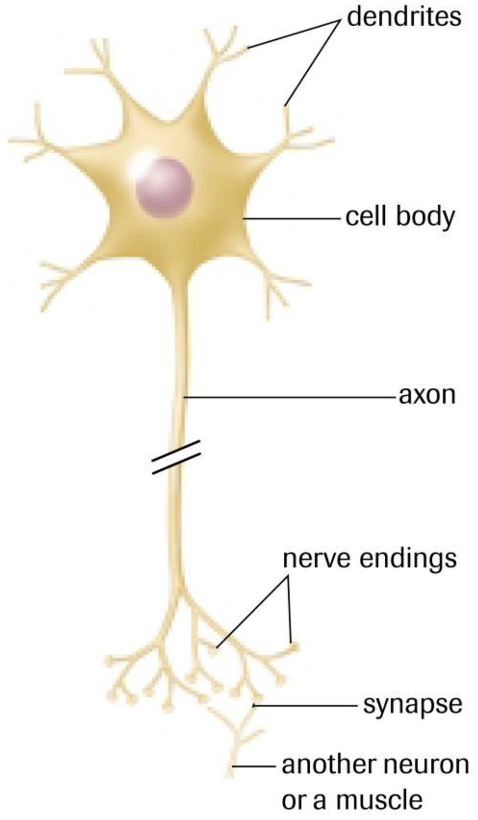
LIGHTNING RODS – CONT.

- Translating this to lightning rods, the tip of the rod is considerably smaller in radius in comparison to other rooftop surfaces
- The electric field near the tip is correspondingly large, ionizing the surrounding air and influencing the path of nearby lightning



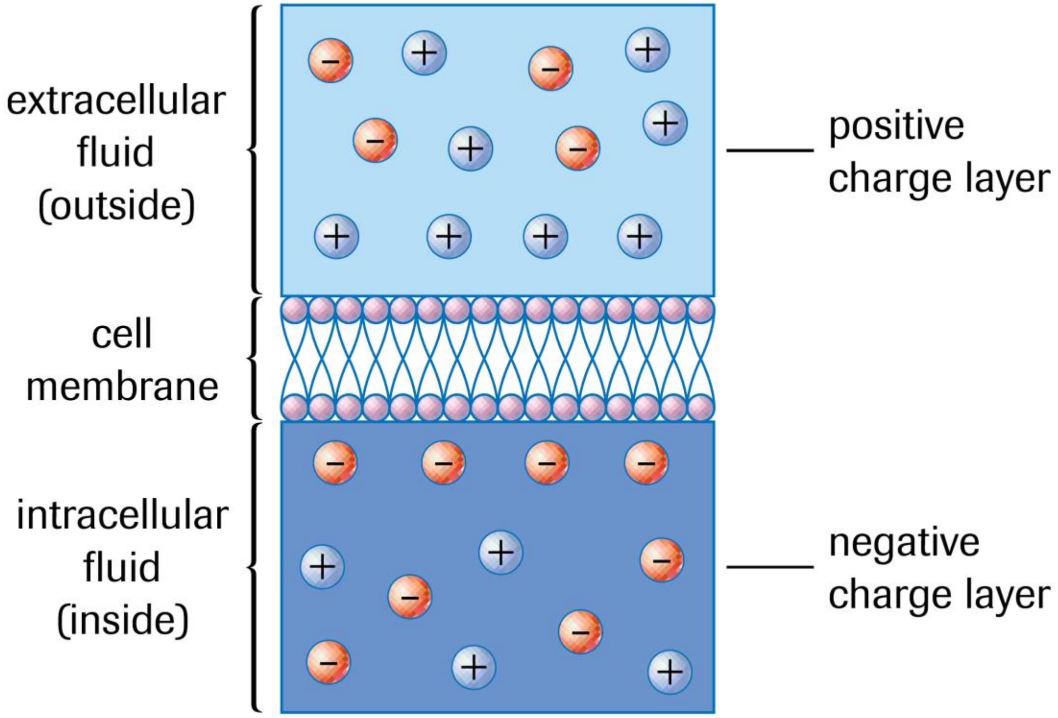
MEDICAL APPLICATIONS

- Neurons use potential difference to send signals through our body
- Dendrites pick up signals from outside the cell and pass them through the axon to the nerve endings
- This gets passed by the nerve endings through the synapse (space) between the next neuron or muscle cell



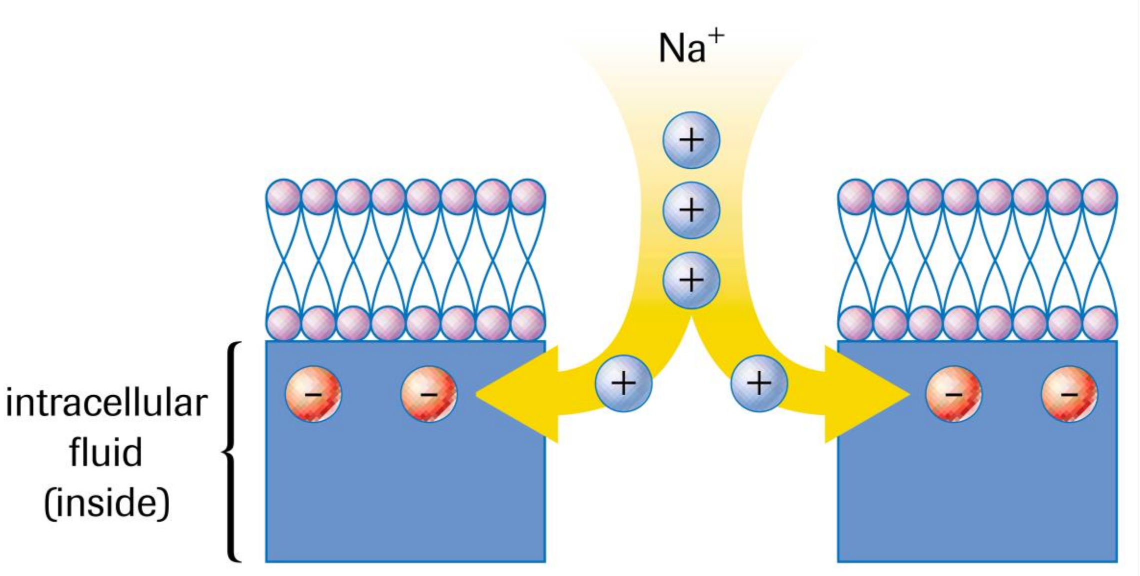
MEDICAL APPLICATIONS – CONT.

- A potential difference is created by a selectively permeable membrane
- "resting" membrane potential difference is -70 mV
  - Negative because inside the cell is negatively charged



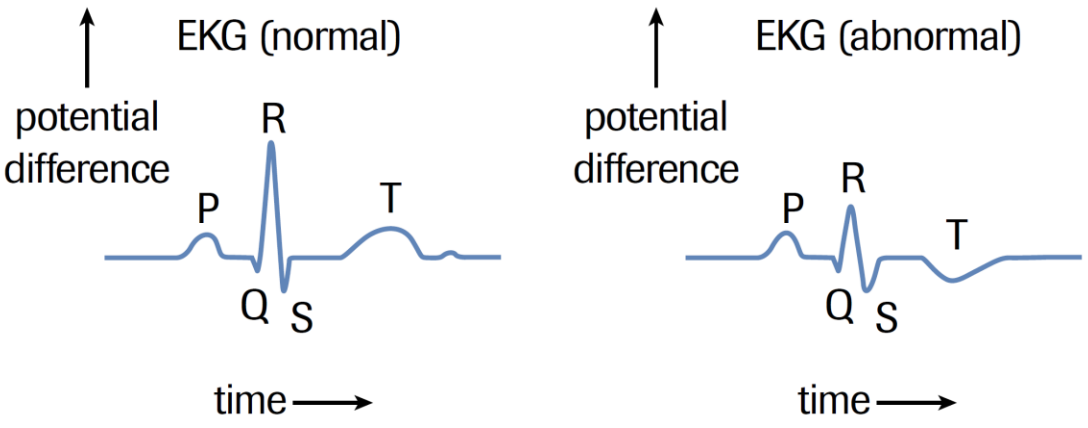
MEDICAL APPLICATIONS – CONT.

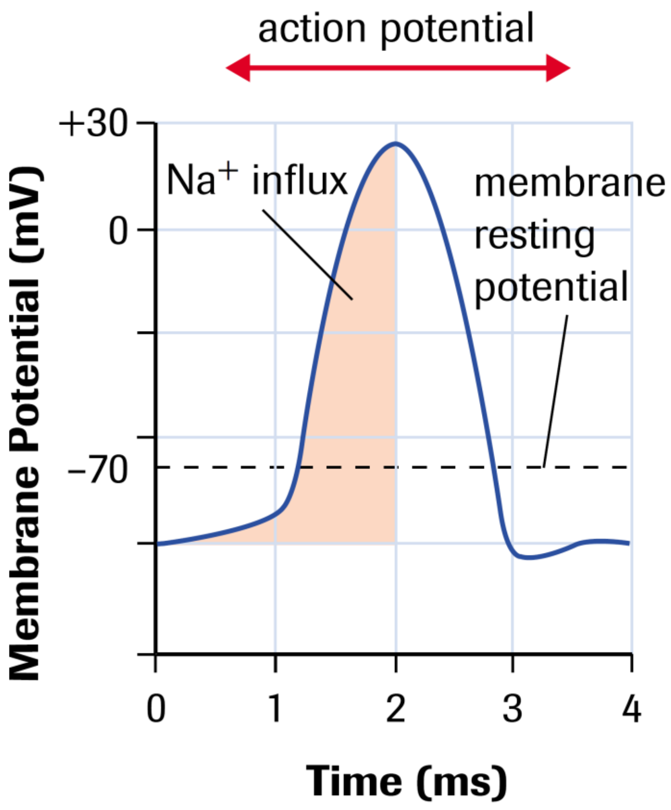
- A strong enough stimulus can open a "gate" in the cell membrane of the dendrite
- Positively charged particles (Na^+) flood the cell, changing the potential difference to $+30$ mV
- This quickly dissipates through the neuron and out the nerve endings to influence the next cell
- The cell returns to -70 mV in a few milliseconds



MEDICAL APPLICATIONS – CONT.

- We can measuring these differences
- Key application: Electrocardiogram (EKG)
  - Verifying the normal heartrate of a patient





SUMMARY – ELECTRICAL POTENTIAL

- The electric potential energy stored in the system of two charges q_1 and q_2 is
$$E_E = \frac{kq_1q_2}{r}$$
- The electric potential a distance r from a charge q is given by
$$V = \frac{kq}{r}$$
- The potential difference between two points in an electric field is given by the change in the electric potential energy of a positive charge as it moves from one point to another:
$$\Delta V = \frac{\Delta E_E}{q}$$
- The magnitude of the electric field is the change in potential difference per unit radius:
$$\varepsilon = \frac{\Delta V}{r}$$

PRACTICE

Readings

- Section 7.4 (pg 349)

Questions

- pg 358 #1-7