# DEVIL PHYSICS

## THE BADDEST CLASS ON CAMPUS

## IB PHYSICS

# TSOKOS LESSON 10-1
# DESCRIBING FIELDS

# Essential Idea:

- Electric charges and masses each influence the space around them and that influence can be represented through the concept of fields.

# Nature Of Science:

- Paradigm shift: The move from direct, observable actions being responsible for influence on an object to acceptance of a field's "action at a distance" required a paradigm shift in the world of science.

# Theory Of Knowledge:

- Although gravitational and electrostatic forces decrease with the square of distance and will only become zero at infinite separation, from a practical standpoint they become negligible at much smaller distances.
- How do scientists decide when an effect is so small that it can be ignored?

# Understandings:

- Gravitational fields
- Electrostatic fields
- Electric potential and gravitational potential
- Field lines
- Equipotential surfaces

# Applications And Skills:

- Representing sources of mass and charge, lines of electric and gravitational force, and field patterns using an appropriate symbolism
- Mapping fields using potential
- Describing the connection between equipotential surfaces and field lines

# Guidance:

- Electrostatic fields are restricted to the radial fields around point or spherical charges, the field between two point charges and the uniform fields between charged parallel plates
- Gravitational fields are restricted to the radial fields around point or spherical masses and the (assumed) uniform field close to the surface of massive celestial bodies and planetary bodies

# Guidance:

- Students should recognize that no work is done in moving charge or mass on an equipotential surface

# Data Booklet References:

$$W = q\Delta V_e$$

$$W = m\Delta V_g$$

# Utilization:

- Knowledge of vector analysis is useful for this sub-topic

# Aim

- Models developed for electric and gravitational fields using lines of forces allow predictions to be made but have limitations in terms of the finite width of a line

# Introductory Video

# The Force of Gravity

# Newton's $2^{nd}$ Law

- Newton's second law (F=ma) implies that if a mass is accelerating, there must be a force acting on it
- An object falls because of gravity
- What holds planets in their orbits?

# Newton's 2nd Law

- Newton's second law (F=ma) implies that if a mass is accelerating, there must be a force acting on it
- An object falls because of gravity
- What holds planets in their orbits?
  - Gravitational Force

# Newton's Law of Gravitation

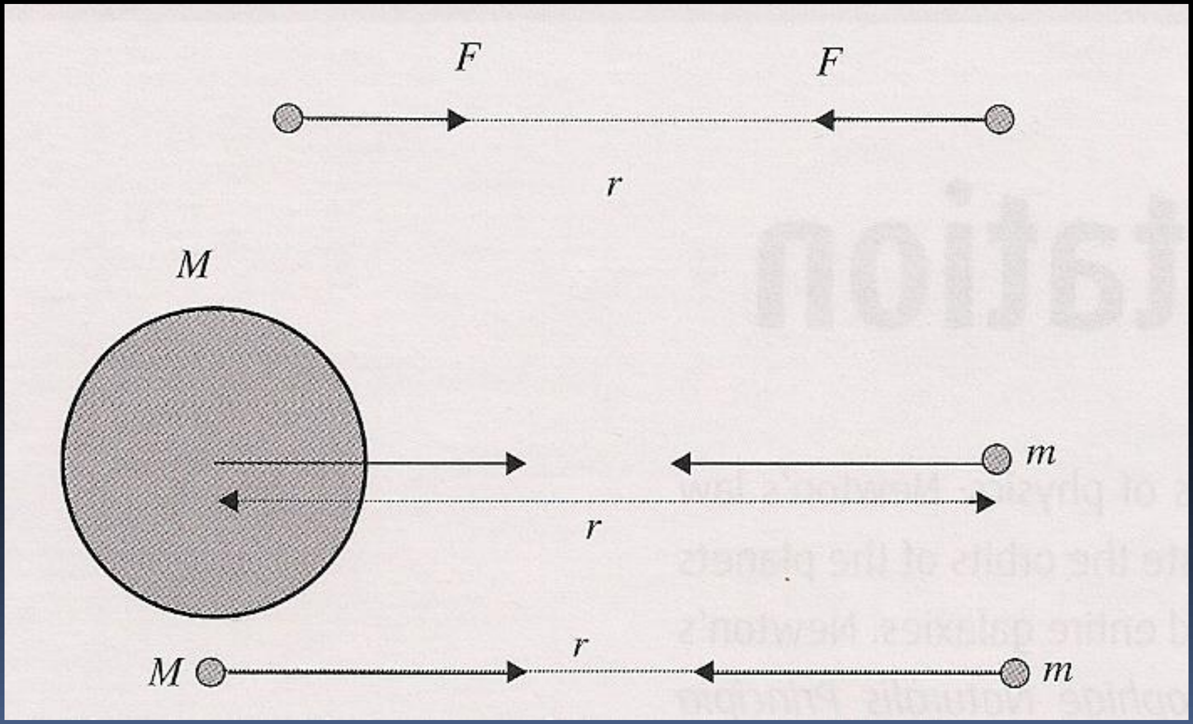
- The attractive force between two point masses is,

$$F = G\frac{M_1 M_2}{r^2}$$

- Where,
  - $M_1$ and $M_2$ are the masses of the attracting bodies
  - r is the distance between them
  - G is Newton's constant of universal gravitation and has a value of $6.667 \times 10^{-11}$ N $m^2$ $kg^{-2}$

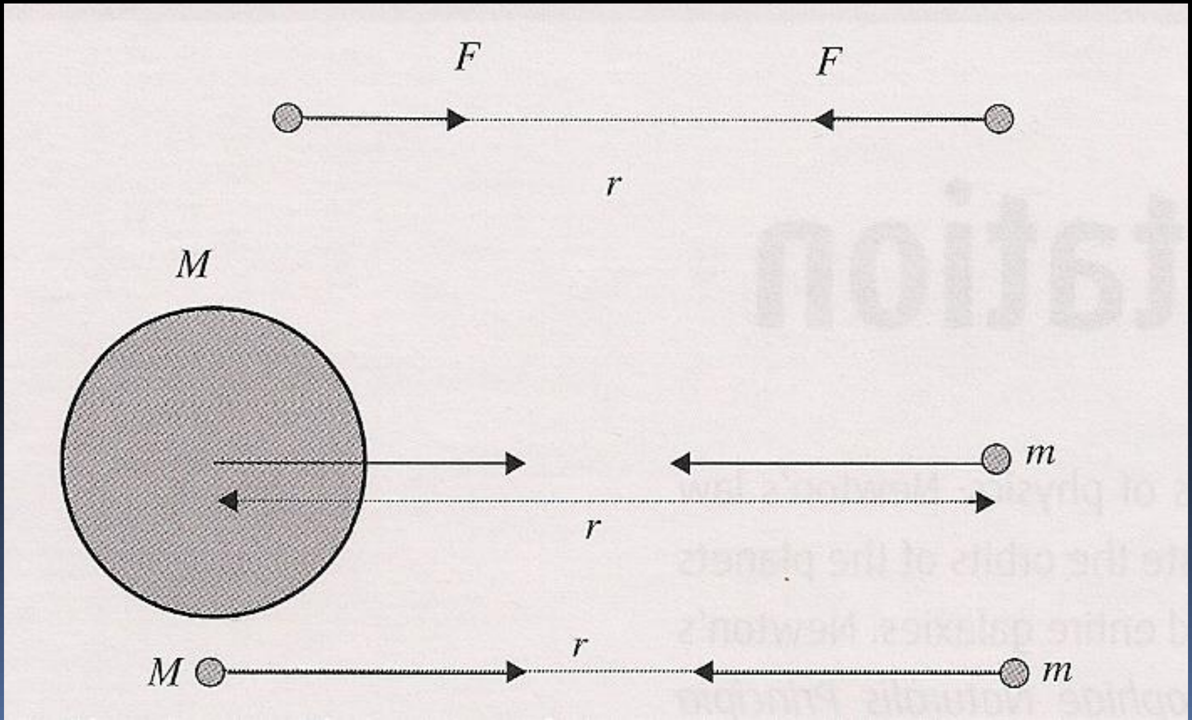
# Newton's Law of Gravitation

- The direction of the force is along the line joining the two masses,



# Newton’s Law of Gravitation

- The formula applies to point masses, which means the masses are small in relation to the separation between them



# Gravitational Field Strength

- The gravitational field strength at a certain point is the force per unit mass experienced by a small point mass, m, at that point.

$$F = G\frac{M_1 m}{r^2}$$

$$F = ma$$

$$ma = G\frac{M_1 m}{r^2}$$

$$a = g = G\frac{M_1}{r^2}$$

# Gravitational Field Strength

- The units of gravitational field strength are $N \cdot kg^{-1}$
- $1N = 1\ kg \cdot m \cdot s^{-2}$
- So units become $m \cdot s^{-2}$

$$F = G\frac{M_1 m}{r^2}$$

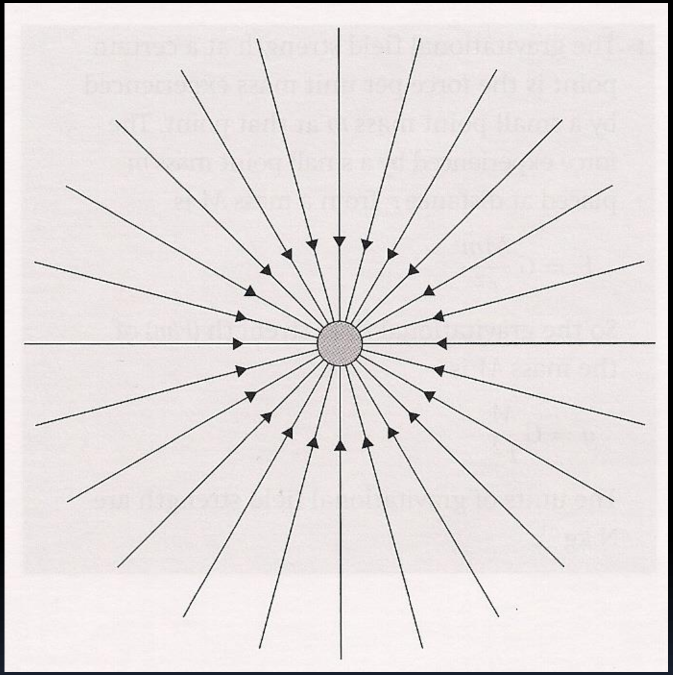
$$F = ma$$

$$ma = G\frac{M_1 m}{r^2}$$

$$a = G\frac{M_1}{r^2}$$

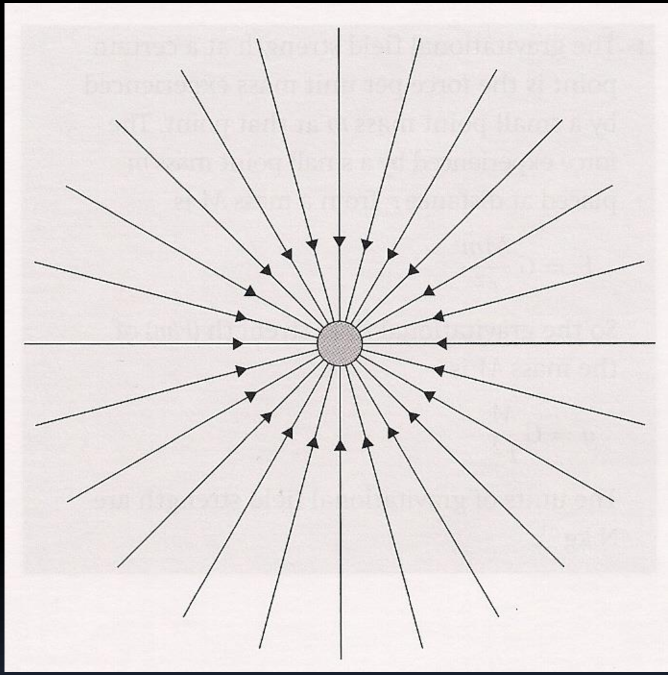
# Gravitational Field Strength

- Gravitational field strength is a vector quantity whose direction is given by the direction of the force a point mass would experience if placed at the point of interest.



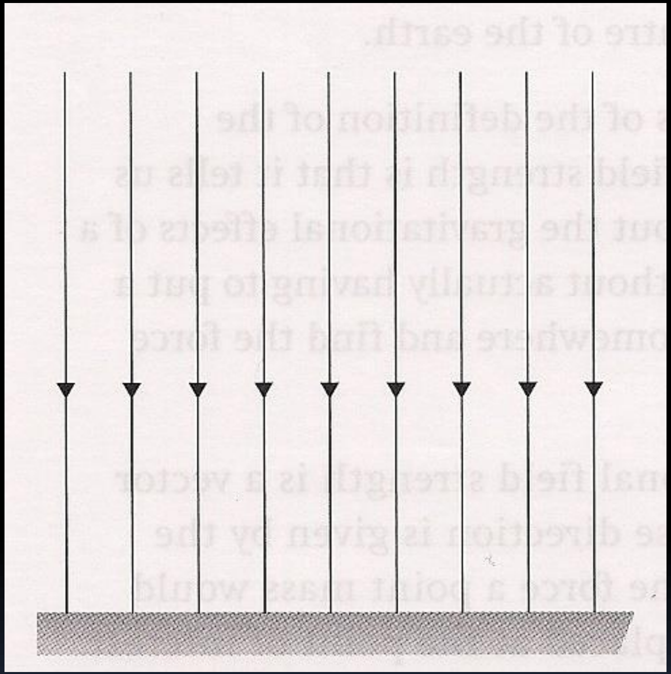
# Gravitational Field Strength

- The gravitational field strength around a single point mass is radial which means it is the same for all points equidistant from the center of mass and directed toward the center.



# Gravitational Field Strength

- On a micro- versus macro-level (like the projectile motion of a football), the field strength can be considered to be uniform with a constant value.



# Gravitational Potential Energy

- The gravitational potential energy of two bodies is the work that was done in bringing the bodies to their present position from infinitely far apart.
- Negative sign signifies a force of attraction

$$F = G\frac{M_1 m}{r^2}$$

$$W = Fxd$$

$$F(r) = G\frac{M_1 m}{r^2}(r)$$

$$W = E_P = -G\frac{M_1 m}{r}$$

# Gravitational Potential ~~Energy~~

- The gravitational potential at a point *P* in a gravitational field is the work done ***per unit mass*** in bringing a small point mass *m* from infinity to point *P*.

$$W = -G\frac{M_1 m}{r}$$

$$V_g = \frac{W}{(m)} = -G\frac{M_1 m}{r(m)}$$

$$V_g = -G\frac{M_1}{r} = -\frac{GM_1}{r}$$

# Gravitational Potential ~~Energy~~

- Gravitational potential is a scalar quantity
- Units are J/kg (work per unit mass)

$$V_g = -\frac{GM_1}{r}$$

# Gravitational Potential ~~Energy~~

- If a point mass *m* is moved from point *P* to point *Q*, it has a change in potential
- It takes work to do this, thus it also has a change in potential energy

$$V_g = -\frac{GM_1}{r}$$

$$W = mV_{g-Q} - mV_{g-P}$$

$$W = \Delta E_P = m\Delta V_g$$

# Gravitational Potential ~~Energy~~

- The work done is dependent only on the change in position, not on the path taken
- The movement must be done at a very small constant speed so that kinetic energy is not involved

$$V_g = -\frac{GM_1}{r}$$

$$W = mV_{g-Q} - mV_{g-P}$$

$$W = \Delta E_P = m\Delta V_g$$

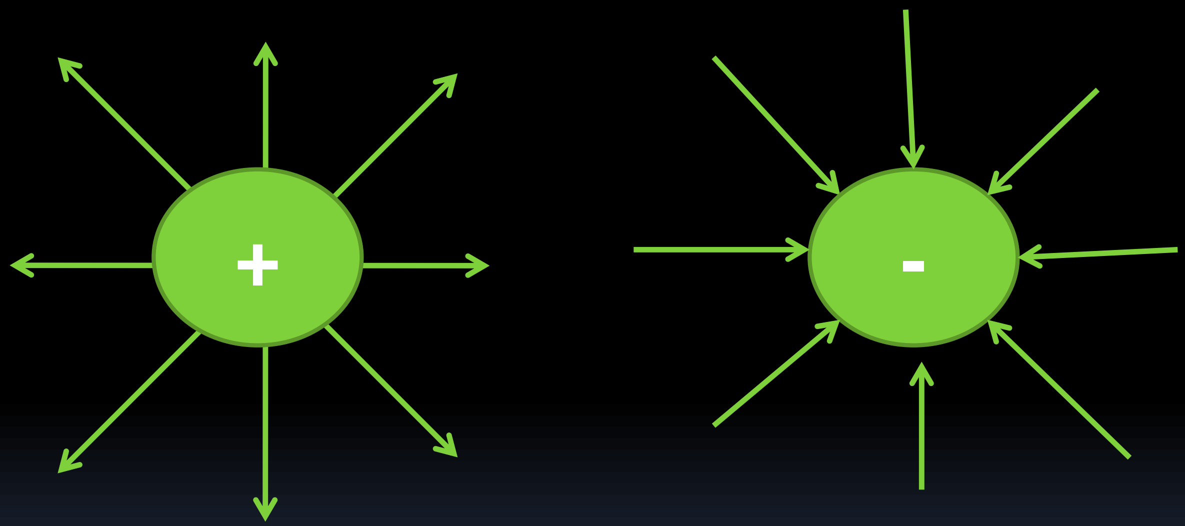
# Introductory Video: Electric Fields and Potential

# Electric Field

- An electric field exists around any charged object and extends/radiates either into or out of the object
  - By convention, charge flows from positive to negative so,
  - For a positively charged object, the field lines extend outward

# Electric Field

- For a positively charged object, the field lines extend outward




- For a negatively charged object, the field lines extend inward

# Electric Field

- The field does not "exist" unless shown to exist by a charge
- We use a ***small positive test charge***, q, to determine if a field exists – bring the test charge close and if it experiences a force, then a field exists

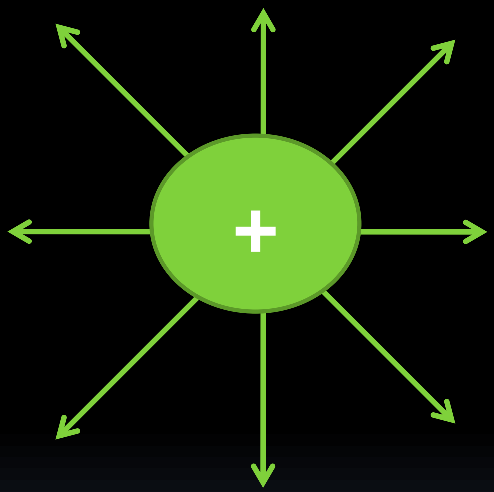
# Electric Field

- Electric field is *defined* as the ***force per unit charge*** experienced by a ***small positive test charge***, q,

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

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

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




The electric field is a vector with **direction** being the same as **the force a positive charge would experience** at the given point

# Electric Field

- **Units for electric field is N/C**

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

$$F = qE$$

# Electric Field

- **The electric field from a single point charge, Q, at a point a distance r away is**

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

$$F = qE$$

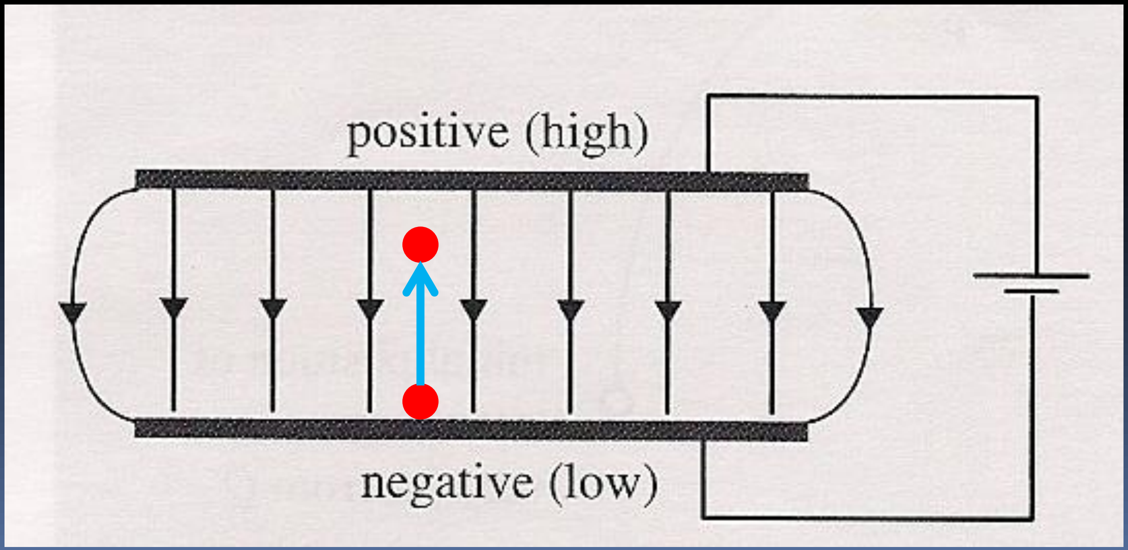
$$F = k\frac{Q_1 q}{r^2}$$

$$qE = k\frac{Q_1 q}{r^2}$$

$$E = k\frac{Q}{r^2}$$

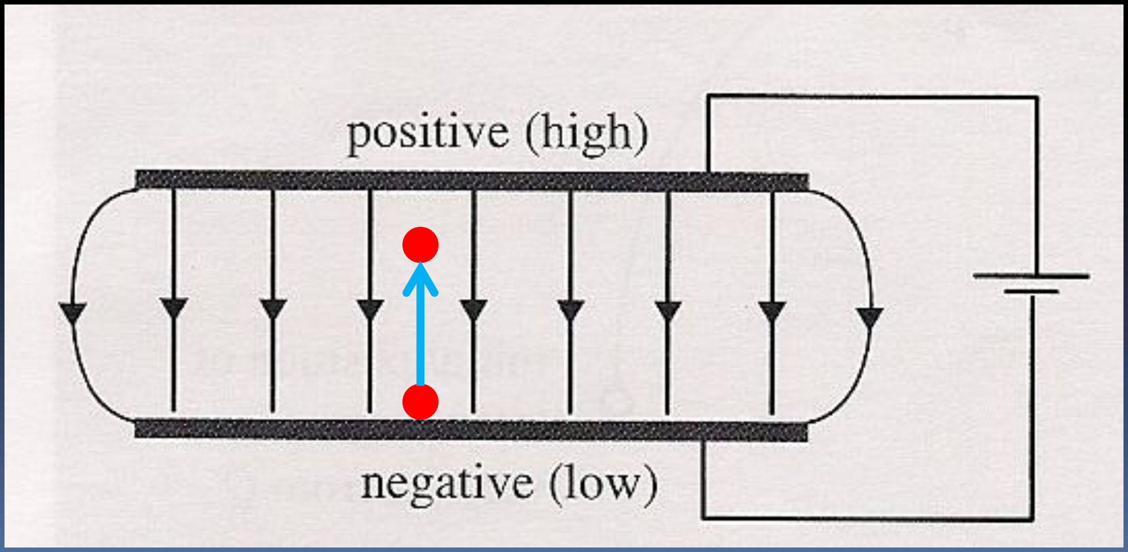
# Electric Potential Energy

- Consider an electric field and a positive test charge q
- In order to move the charge from its equilibrium position, work must be done



# Electric Potential Energy

- If held in that new position, the test charge now has potential energy like a compressed spring because it wants to go back to its equilibrium position



# Electric Potential Energy

- It takes work to move the charge from one places to another
- The amount of work is equal to the change in potential energy

$$F = k\frac{Q_1 q}{r^2}$$

$$W = Fxd = E_P$$

$$E_P = k\frac{Q_1 q}{r^2}(r)$$

$$E_P = k\frac{Q_1 q}{r}$$

# Electric Potential ~~Energy~~

- Just as gravitational potential ($V_g$) is equal to work per unit mass, electric potential ($V_e$) is equal to work per unit charge

$$V_g = \frac{W}{m}$$

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

$$V_e = \frac{kQq}{r}\left(\frac{1}{q}\right)$$

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

# Electric Potential ~~Energy~~

- The electric potential at a point *P* is the amount of work done per unit charge as a small positive test charge *q* is moved from infinity to the point *P*.
- The unit of potential is the volt (V), and 1V = 1J/C

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

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

# Electric Potential

- "V" is the electric potential and is defined in terms of the work, W, needed to bring a positive test charge, q, from very far away to a position close to the charged body

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

*Remember that work is based on displacement and not distance travelled!*

$$qV_e = W$$

# Potential Difference

- **The amount of work needed to move a test charge from one point to another is equal to the change in potential energy of the charge**
- **Just like gravity**

$$W = \Delta U$$

$$W = U_B - U_A$$

$$W = qV_B - qV_A$$

$$W = q\left(V_B - V_A\right)$$

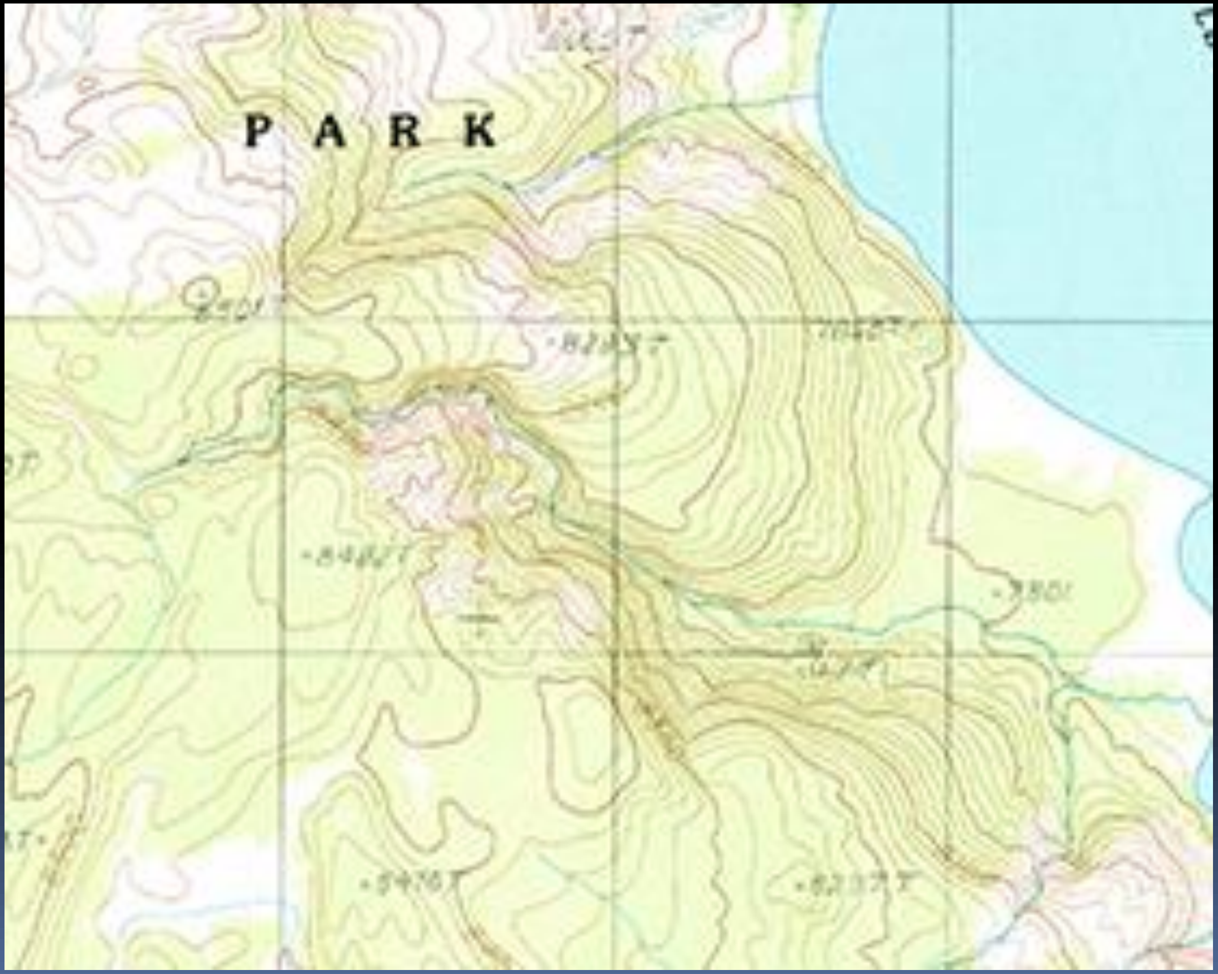
# Summary

| | Force | Field | Potential | Potential Energy |
|---|---|---|---|---|
| Gravity | $F_g = \frac{GMm}{r^2}$ | $g = \frac{GM}{r^2}$ | $V_g = \frac{GM}{r}$ | $E_{P-g} = \frac{GMm}{r}$<br>$E_{P-g} = m\Delta V_g$ |
| Electricity | $F_e = \frac{kQq}{r^2}$ | $E = \frac{kQ}{r^2}$ | $V_e = \frac{kQ}{r}$ | $E_{P-e} = \frac{kQq}{r}$<br>$E_{P-e} = m\Delta V_e$ |

# Video: Equipotentials and Fields

# Equipotential Surfaces

- What is this?

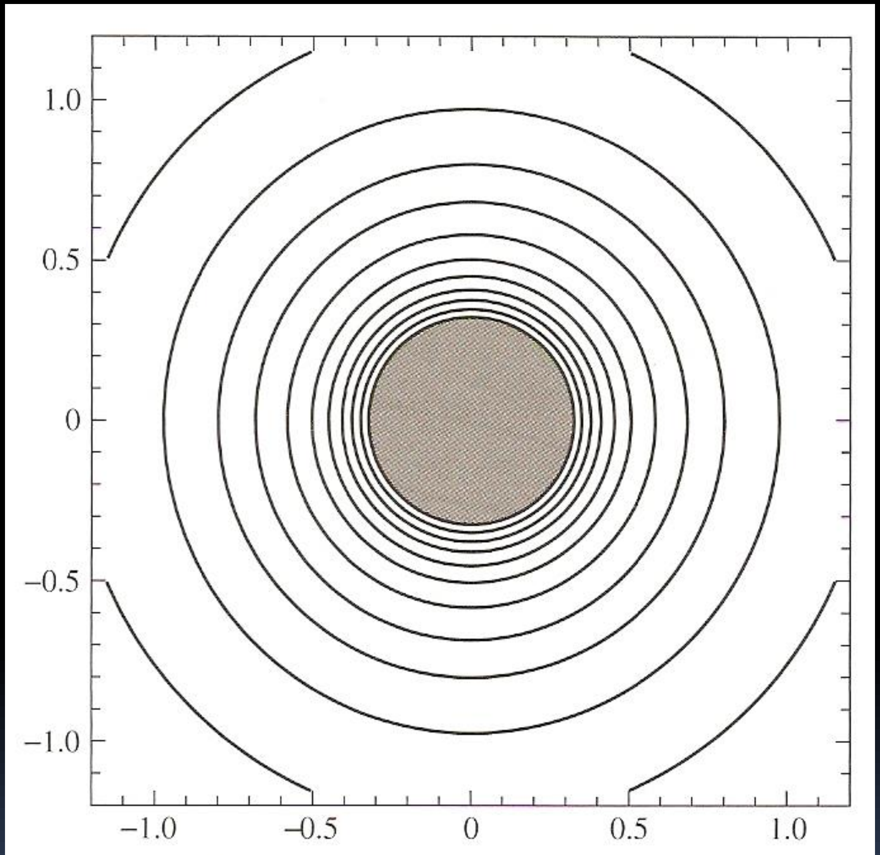


# Equipotential Surfaces

- Gravitational potential is given by

$$V = -\frac{GM}{r}$$

- An equipotential surface consists of those points that have the same potential



# Equipotential Surfaces

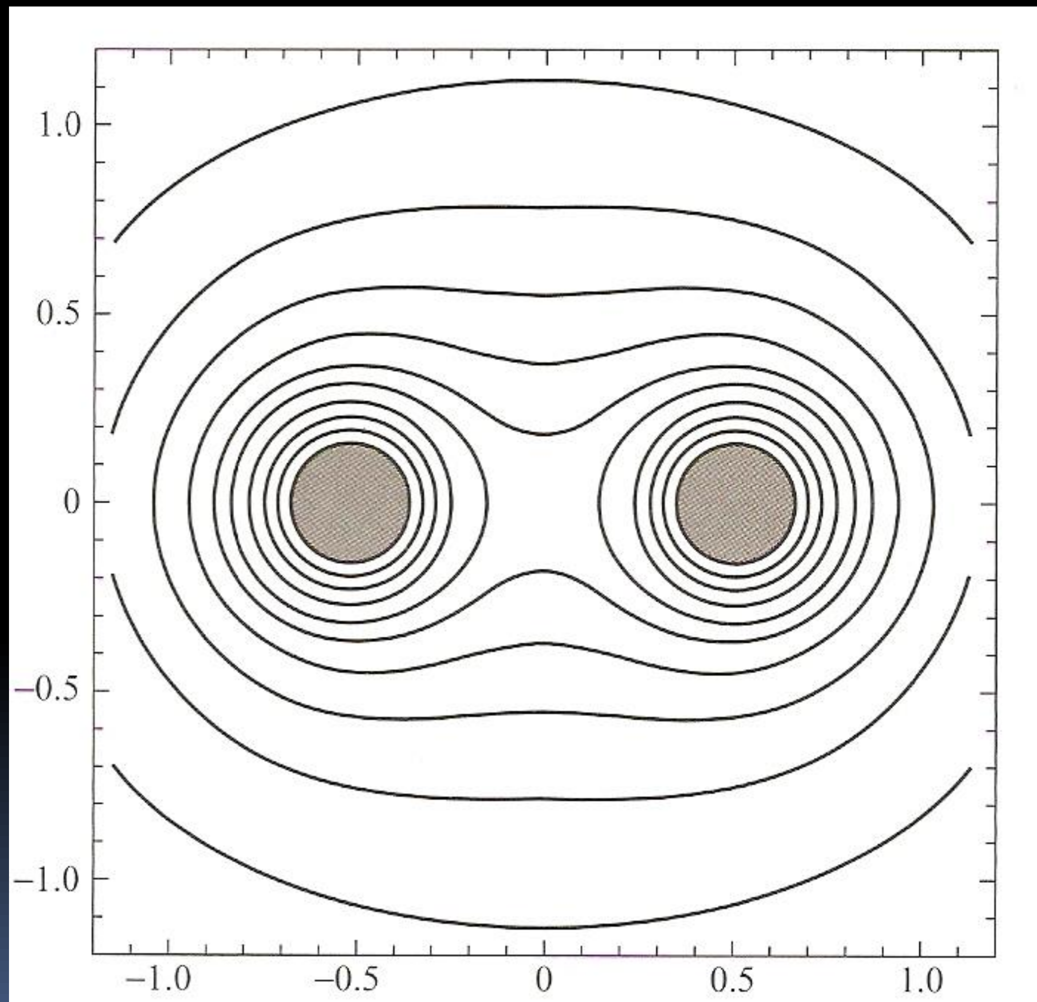
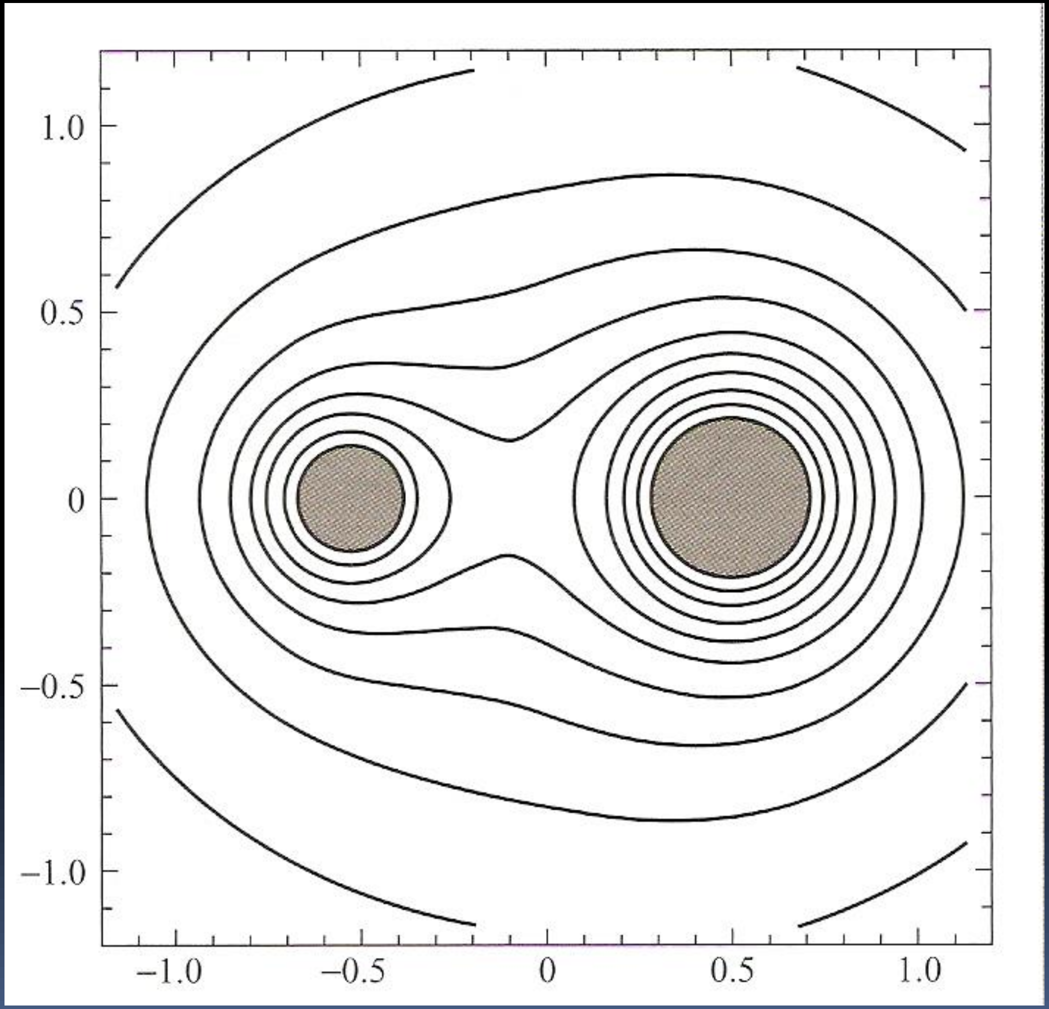


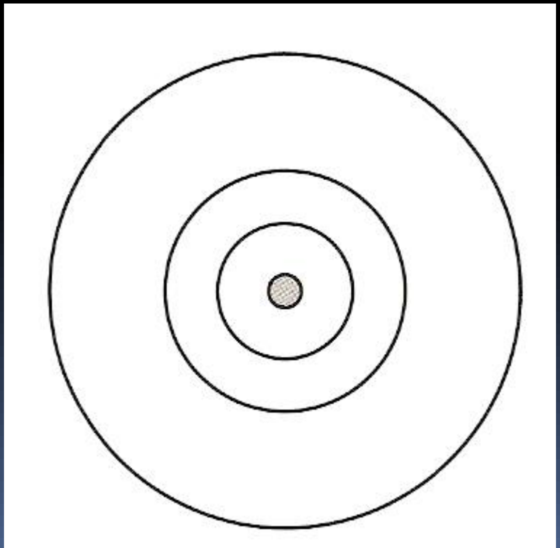

Figure 11.10 The equipotential surfaces due to two

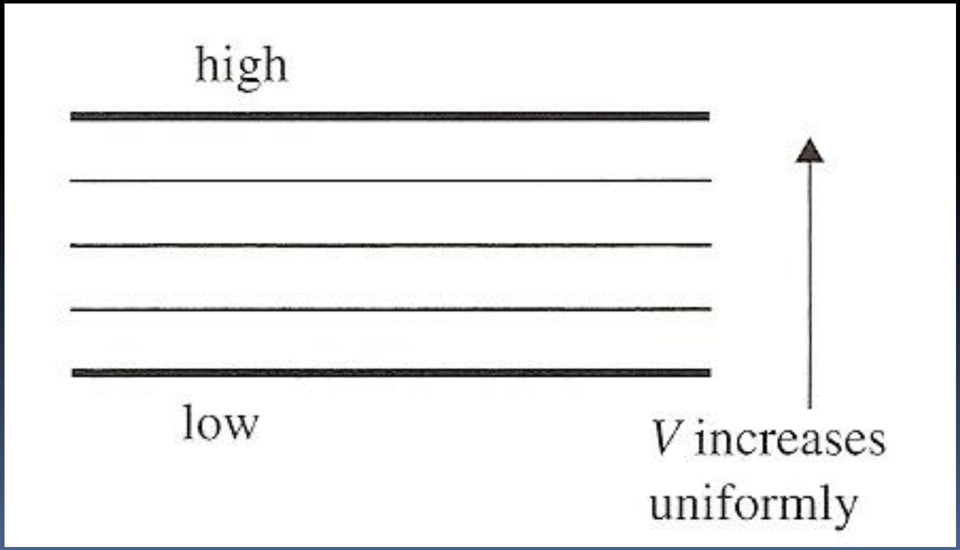
# Equipotential Surfaces



# Equipotential Surfaces

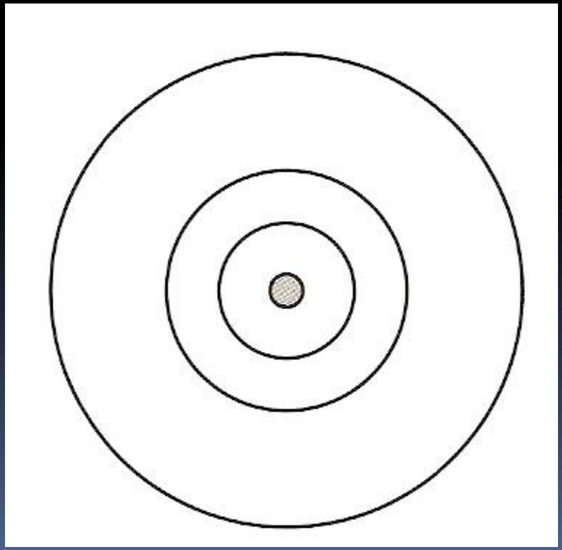
- For electricity, equipotential surfaces or lines are areas where the potential around a charge are equal, just like the contour lines on a topographical map

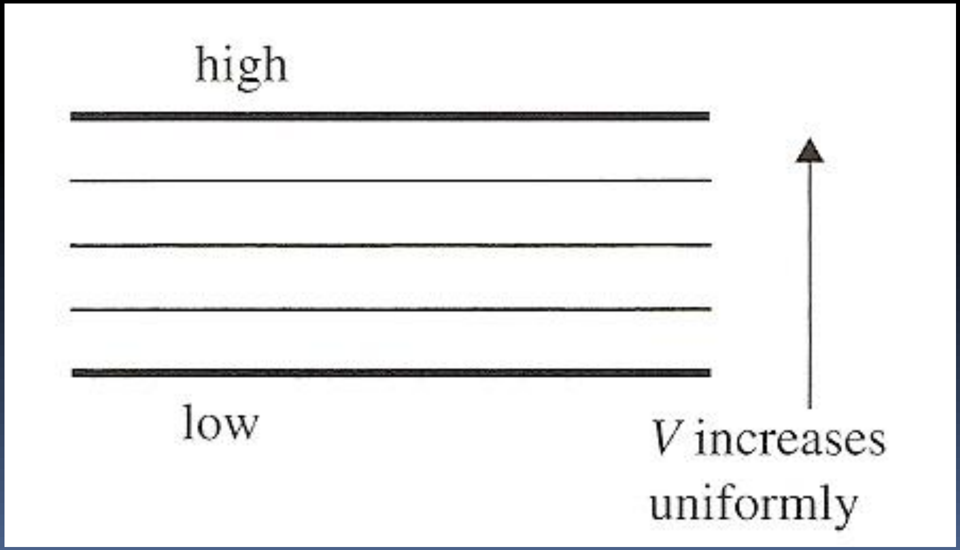




# Equipotential Surfaces

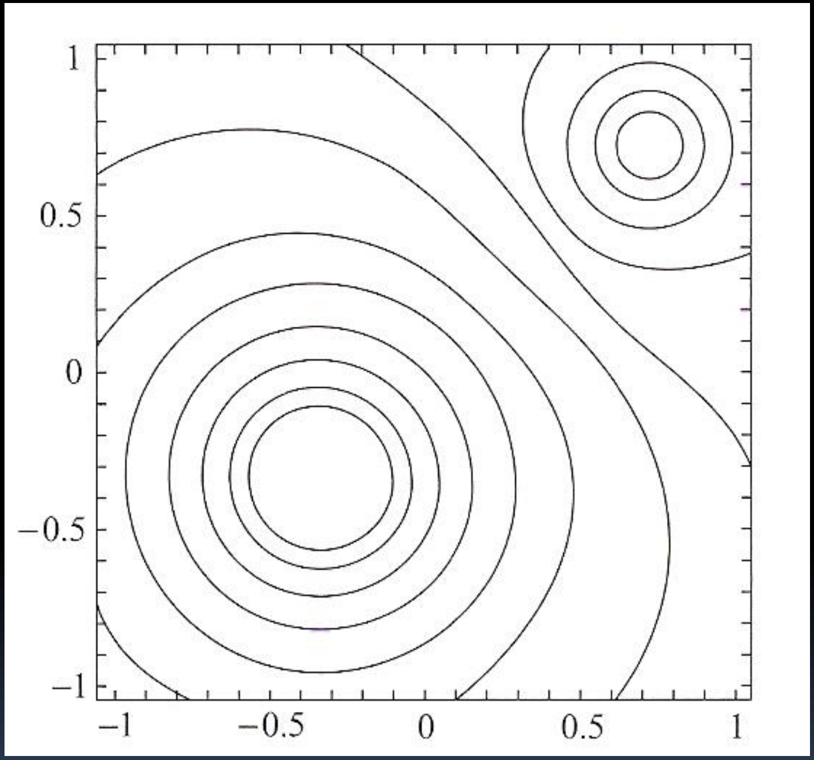
- All points a given distance from the center of a sphere will have the same potential
- All points a given perpendicular distance from a parallel plate will have the same potential





# Equipotential Surfaces

- Equipotential lines for two opposite charges of different magnitudes
- Movement along an equipotential line requires no work because there is no change in potential



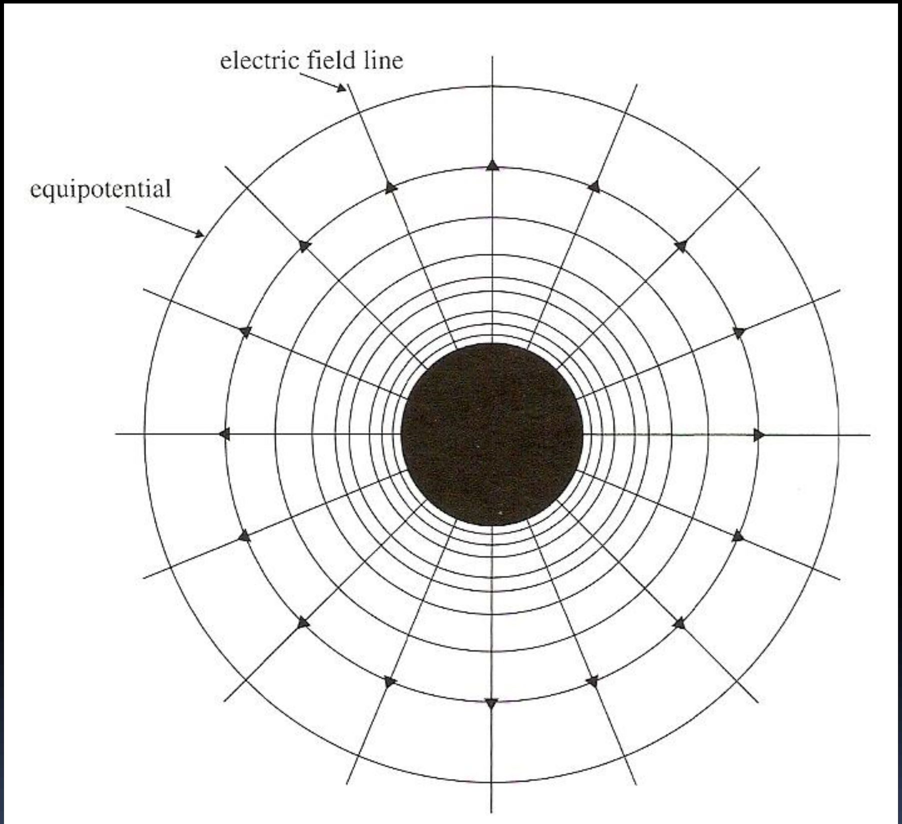
# Connection Between Electric Field and Electric Potential

- The electric field strength (E) is equal to the change in potential divided by the distance over which that change takes place
- *Thus the field strength is equal to the potential gradient*
- If the potential is constant, the field strength is zero
- Potential inside a sphere is constant so the field is zero

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

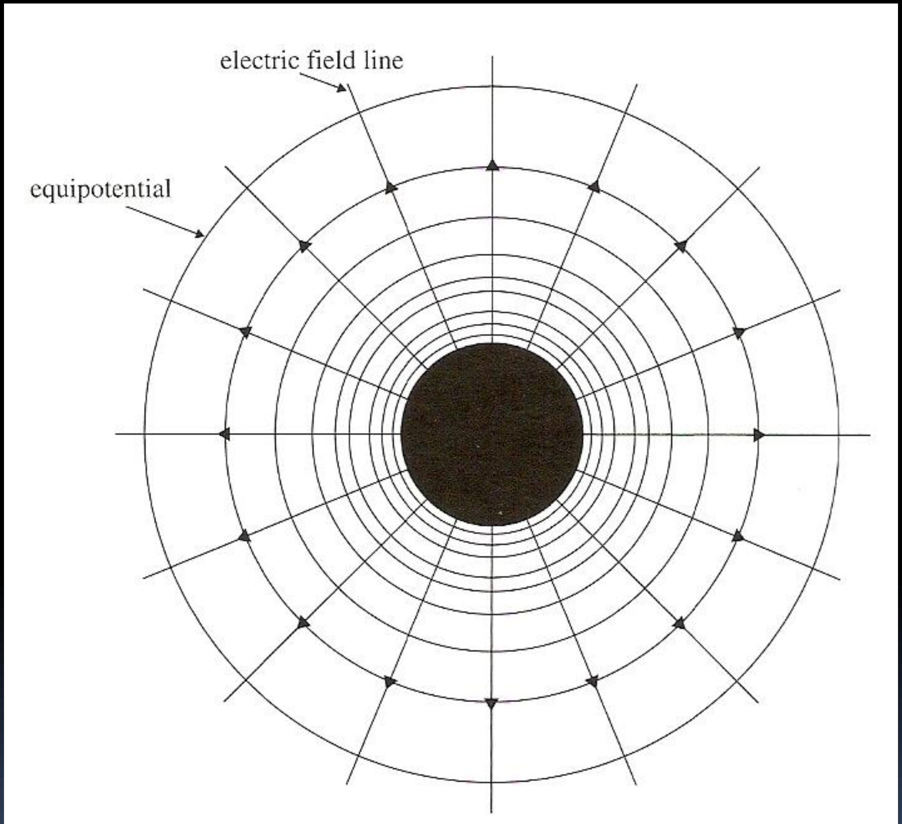
# Connection Between Electric Field and Electric Potential

- Since there is no potential difference along an equipotential line, the field is zero along those lines



# Connection Between Electric Field and Electric Potential

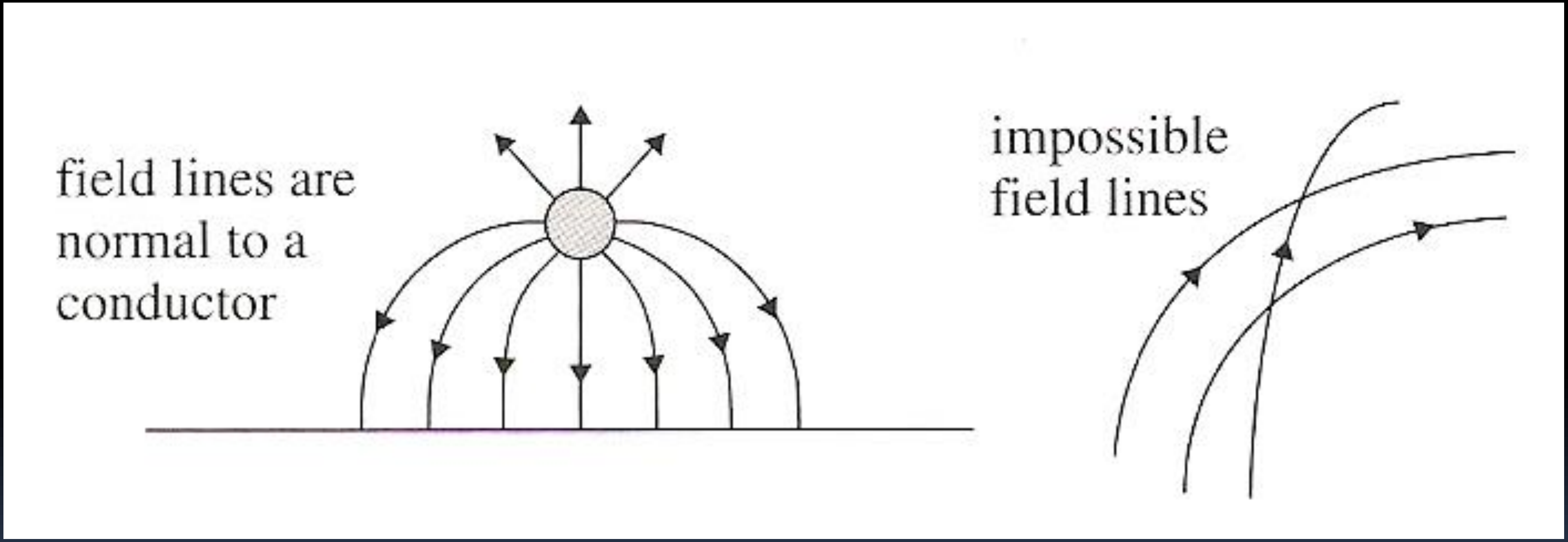
- Since there IS a potential difference BETWEEN equipotential lines, and because field strength is based on displacement, the electric field is must be normal to those lines



# Connection Between Electric Field and Electric Potential

- The surfaces of conductors are areas of equipotential
- Field lines run perpendicular to the surface of conductors
- If they didn't there would be a component parallel to the equipotential surface and that can't happen

# Connection Between Electric Field and Electric Potential



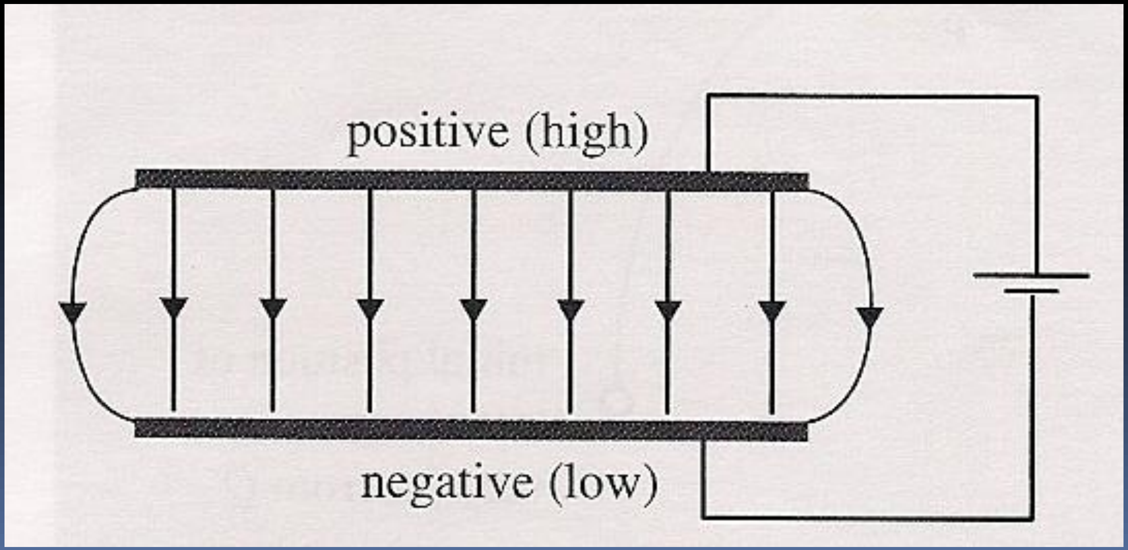
# Electricity Vs Gravitation

- Comparison of Newton's Law of Gravitation and Coulomb's Law

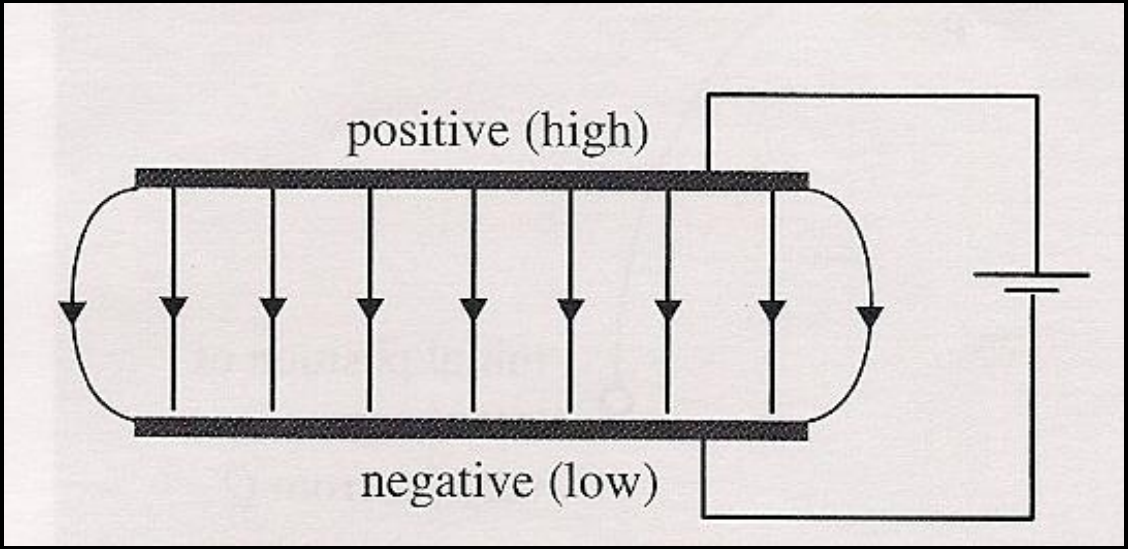
| | Gravitation | Electricity |
|---|---|---|
| Acts on | Mass (positive only) | Charge (positive or negative) |
| Force | $F = G\frac{M_1 M_2}{r^2}$<br>Attractive only<br>Infinite range | $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r}$<br>Attractive or repulsive<br>Infinite range |
| Relative strength | 1 | $10^{42}$ |
| Field | $g = G\frac{M}{r^2}$ | $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$ |
| Potential | $V = -G\frac{M}{r}$ | $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ |
| Work done | Independent of path | Independent of path |
| Potential energy | $U = -G\frac{Mm}{r}$ | $U = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r}$ |

# Parallel Plates

- ***Uniform Electric Field*** **exists when the field has a constant magnitude and direction such as that generated by two oppositely charged parallel plates.**



# Parallel Plates

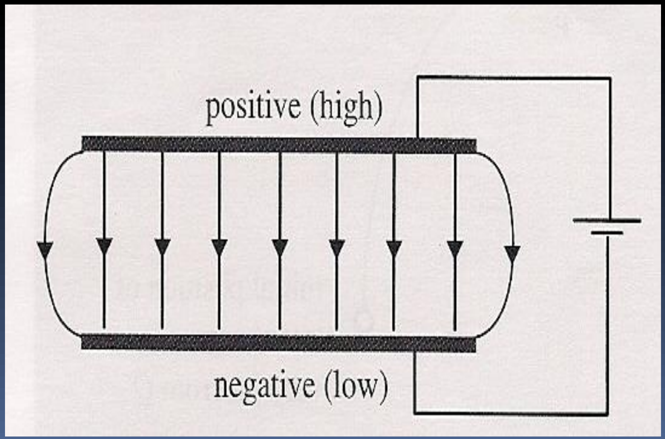



- The field lines at the edges begin to curve
- The field is uniform if the length of the field is large compared to the distance between the plates

# Electric Field between parallel plates

- The electric field, *E*, between two parallel plates is equal to the potential difference between the plates, *V*, divided by the distance between the plates, *d*
  - Note that *E* is the electric field – *E* does not stand for energy!

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



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# Applications And Skills:

- Representing sources of mass and charge, lines of electric and gravitational force, and field patterns using an appropriate symbolism
- Mapping fields using potential
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# Essential Idea:

- Electric charges and masses each influence the space around them and that influence can be represented through the concept of fields.

QUESTIONS?

# Homework

#1-21