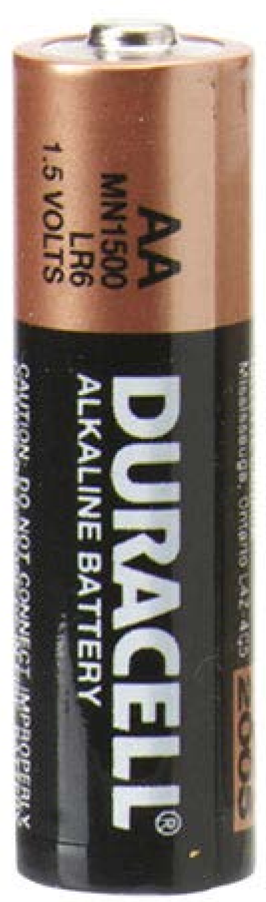
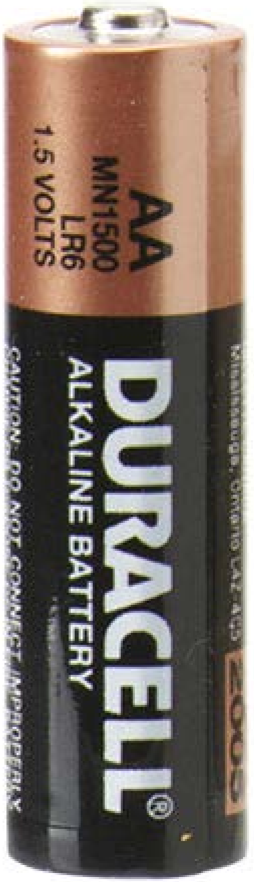
Chapter 22 : Electric potential

- What is electric potential?
- How does it relate to potential energy?
- How does it relate to electric field?
- Some simple applications



Electric potential

- What does it mean when it says "1.5 Volts" on the battery?

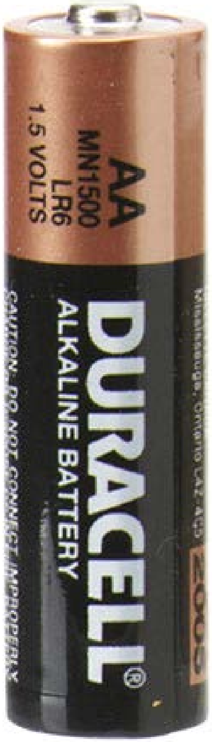


- The electric potential difference between the ends is 1.5 Volts

Electric potential

230 V

1.5 V



100,000 V

So what is a volt?

Electric potential

- The electric potential difference ΔV in volts between two points is the work in Joules needed to move 1 C of charge between those points

$$W = q \times \Delta V$$

W = work done [in J]
q = charge [in C]
ΔV = potential difference [in V]

- ΔV is measured in volts [V] : 1 V = 1 J/C

Electric potential

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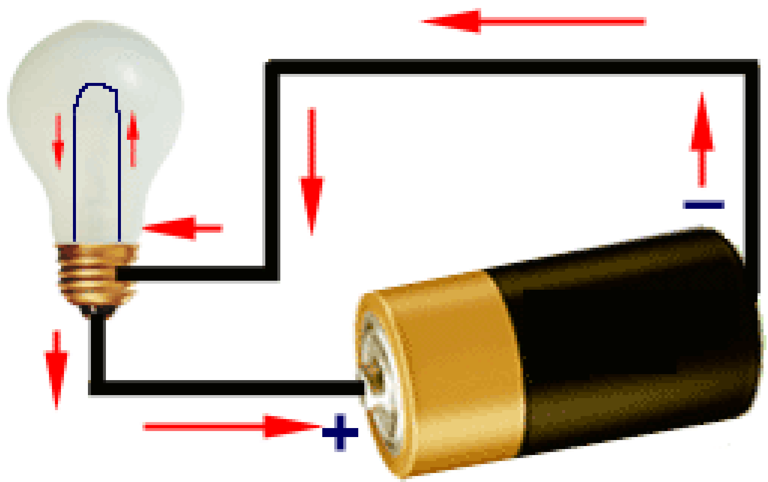
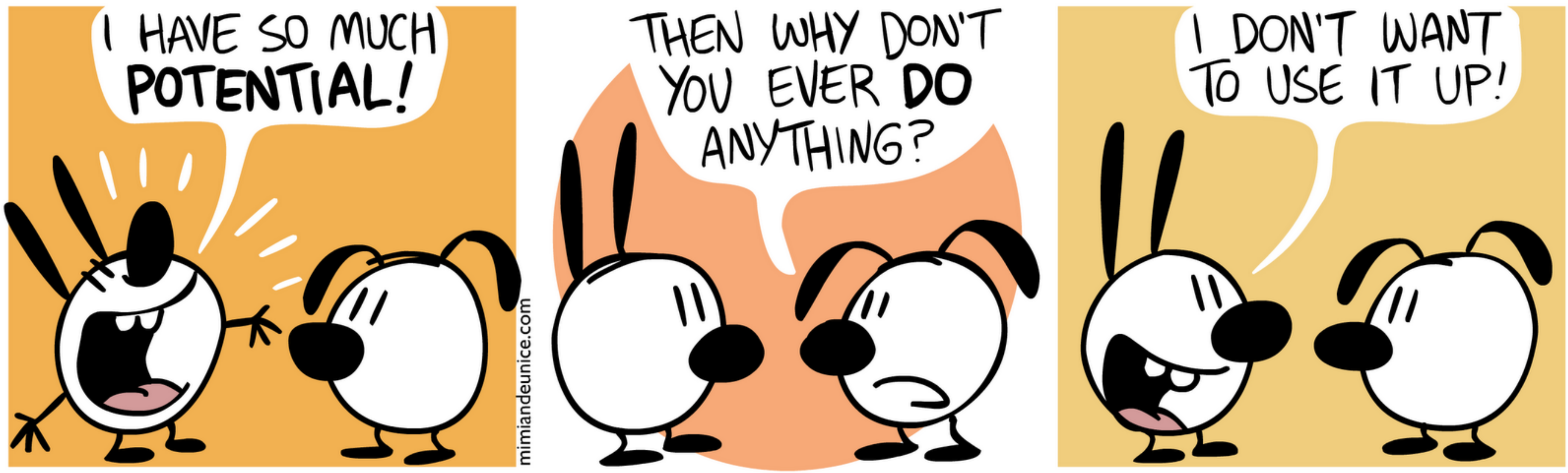


Simple circuit with light

The 1.5 V battery does 1.5 J of work for every 1 C of charge flowing round the circuit

Potential energy

- What is this thing called "potential"?



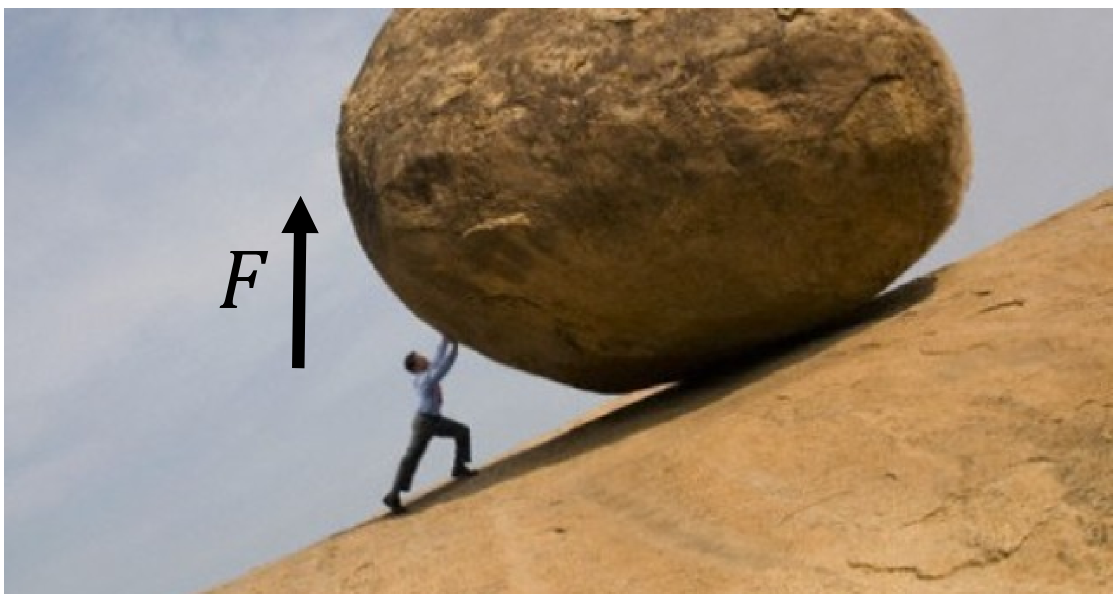
- Potential energy crops up everywhere in physics

Potential energy

- Potential energy U is the energy stored in a system (when work is done against a force)

- e.g. force of gravity …

$$F = mg$$



Work = Force x Distance

h

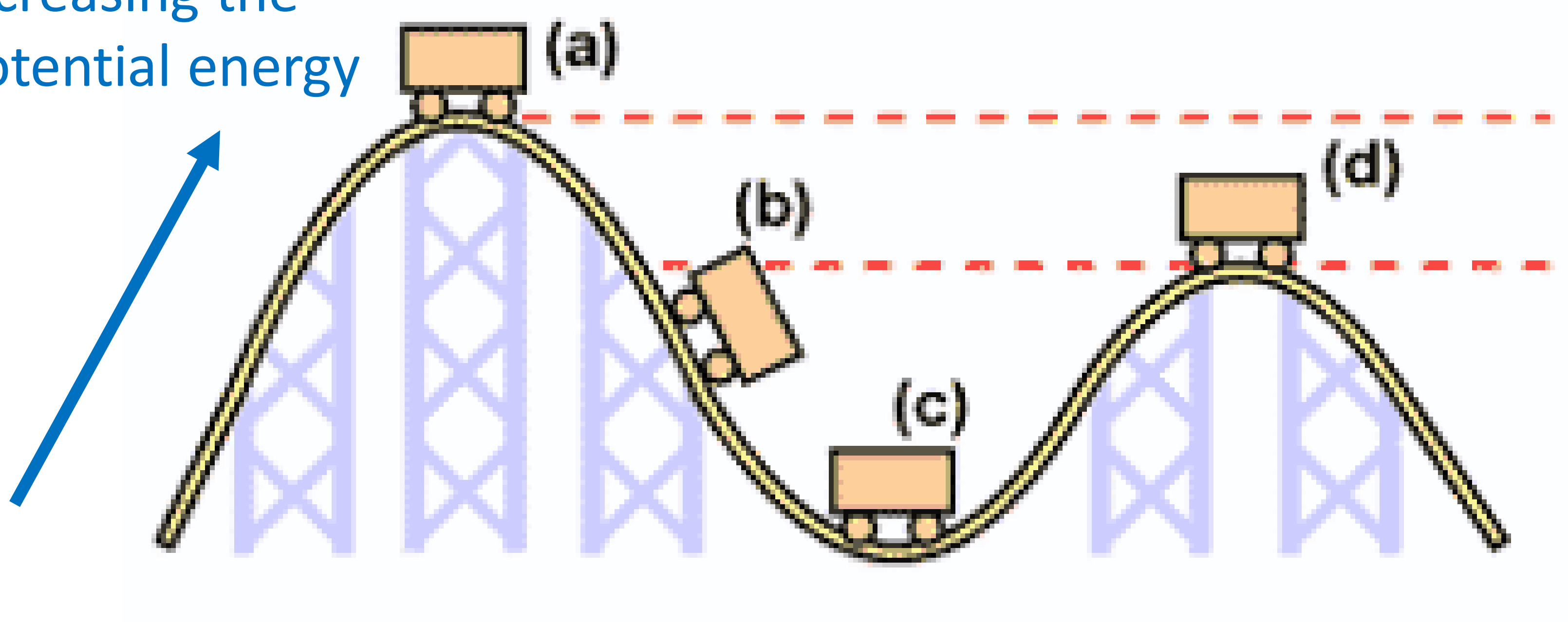
$$W = F \times h$$
$$= mgh$$

$$\rightarrow U = mgh$$

Potential energy

- Potential energy may be released and converted into other forms (such as kinetic energy)

Work is done, increasing the potential energy



Potential energy

- Potential energy difference is the only thing that matters – not the reference (or zero) level
- For example, applying conservation of energy to a mechanics problem:

Final energy = Initial energy

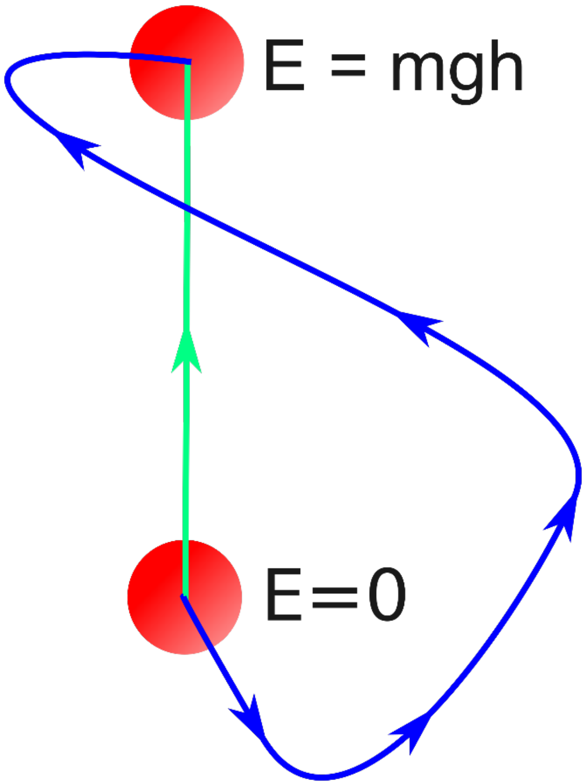
$$KE_{final} + PE_{final} = KE_{initial} + PE_{initial}$$

$$KE_{final} = KE_{initial} + (PE_{initial} - PE_{final})$$

Difference in potential energy

Potential energy

- Potential energy difference doesn't depend on the path – only on the two points A and B



Potential energy

- Potential energy U is the energy stored in a system – second example

- e.g. stretching a spring …

$$F = kx$$

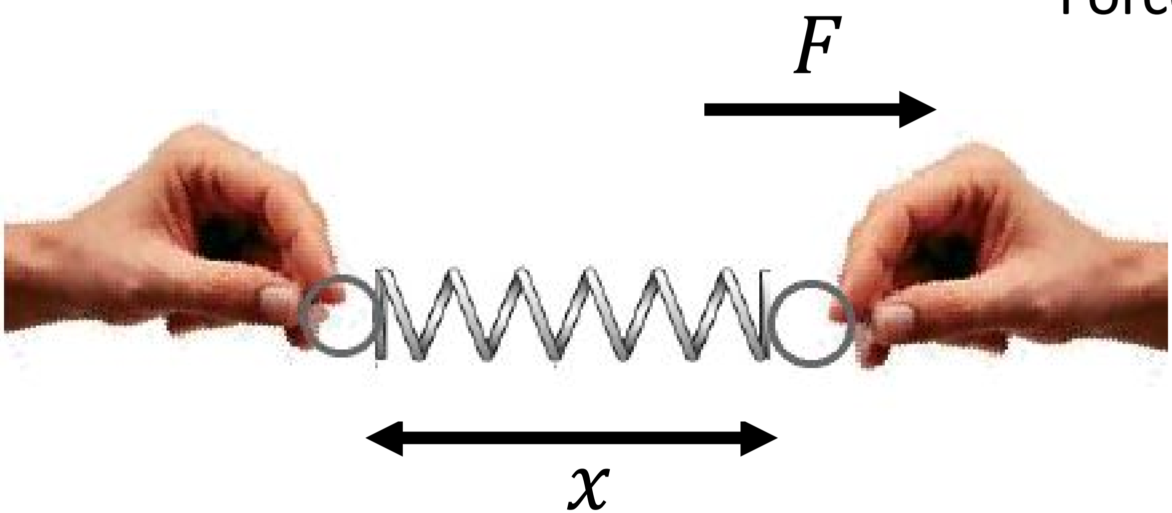
Work = Force x Distance

Force is varying with distance!

$$W = \int kx\, dx$$

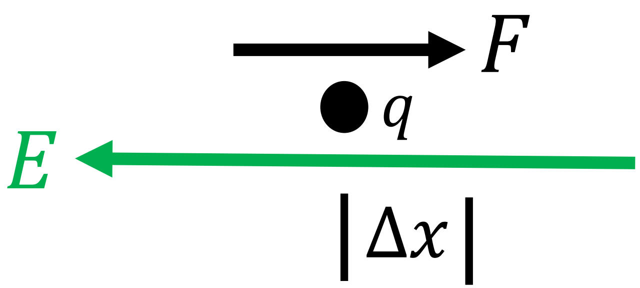
$$= \frac{1}{2}kx^2$$

$$\rightarrow U = \frac{1}{2}kx^2$$



Electric potential

- e.g. moving a charge through an electric field…



$$F = -qE$$

(minus sign because the force is opposite to E)

Work = Force x Distance

$$W = F\,\Delta x \quad = -qE\,\Delta x$$

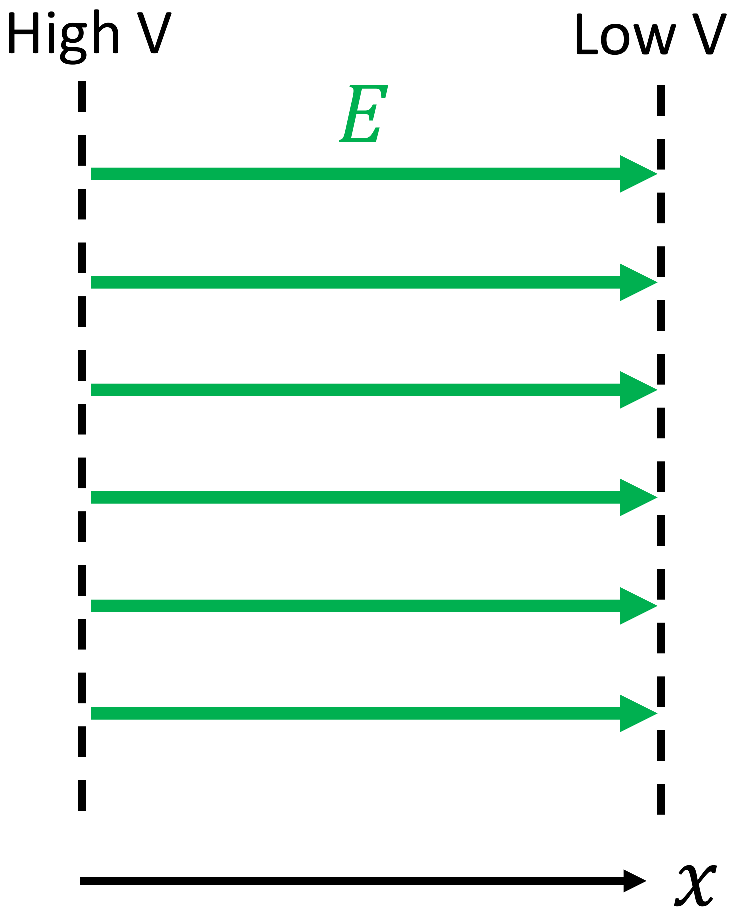
- Potential difference ΔV is work needed to move 1C of charge: $W = q\,\Delta V$

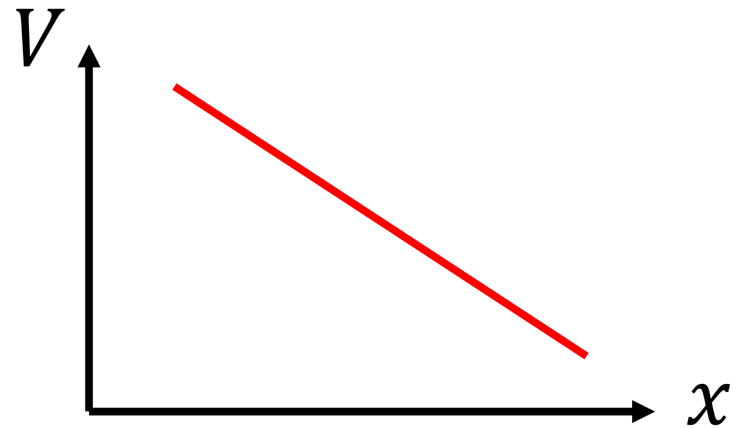
- Equate: $q\,\Delta V = -qE\,\Delta x$

$$E = -\frac{\Delta V}{\Delta x}$$

Electric potential

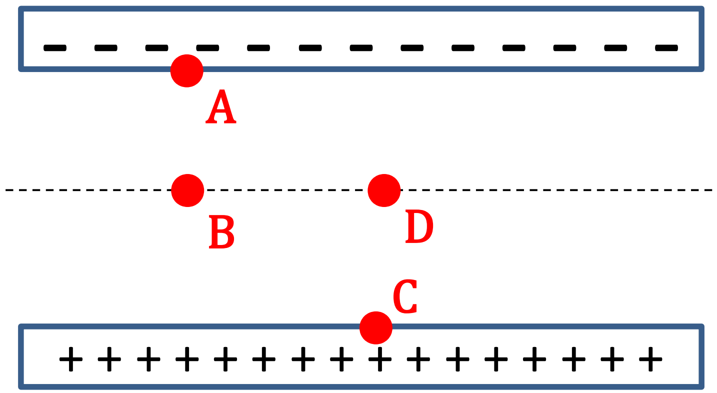
- Electric field is the gradient of potential $E = -\frac{\Delta V}{\Delta x}$



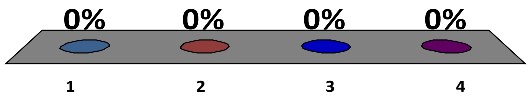


- Positive charges feel a force from high to low potential
- Negative charges feel a force from low to high potential

Two parallel plates have equal and opposite charge. Rank the indicated positions from highest to lowest electric potential.

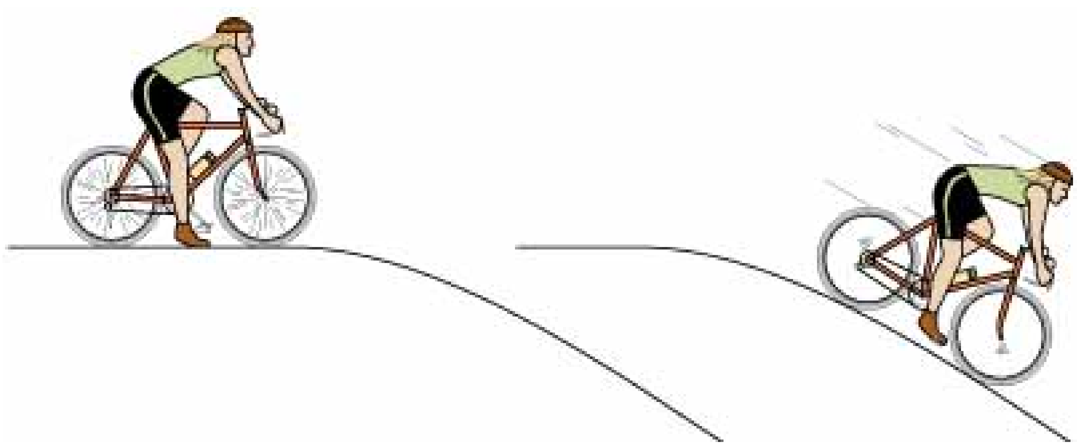


1. A=C, B=D
2. A, B, C, D
3. C, D=B, A
4. A, B=D, C



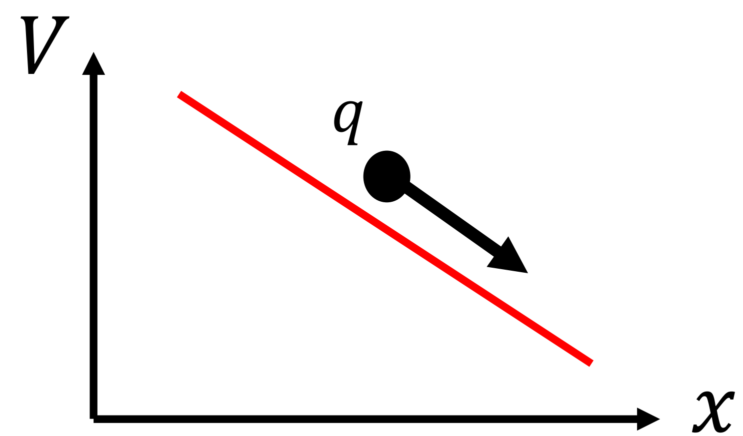
Electric potential

- Analogy with gravitational potential



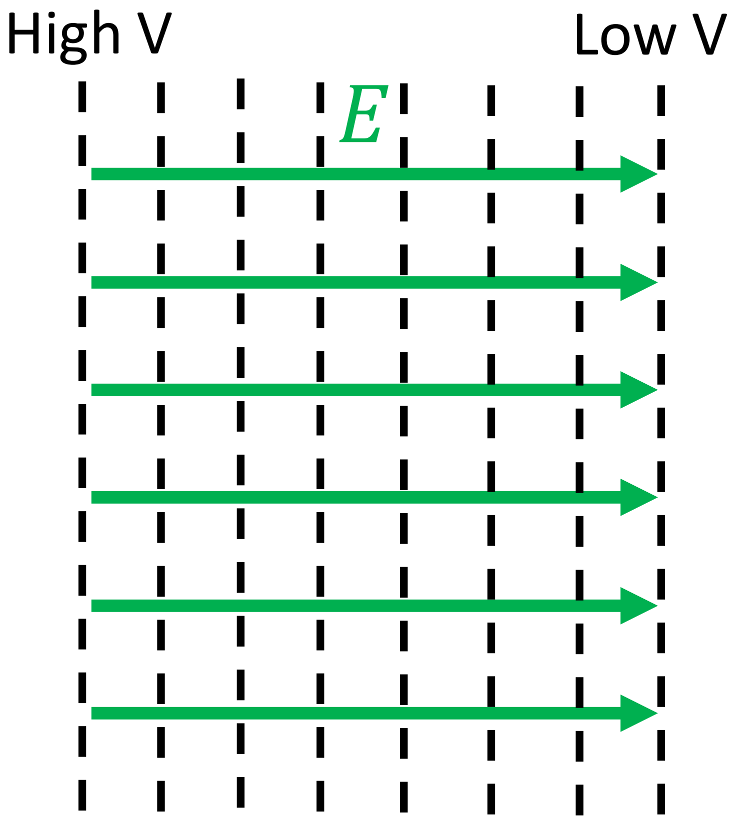
Gravitational potential difference exerts force on mass

Electric potential difference exerts force on charge



Electric potential

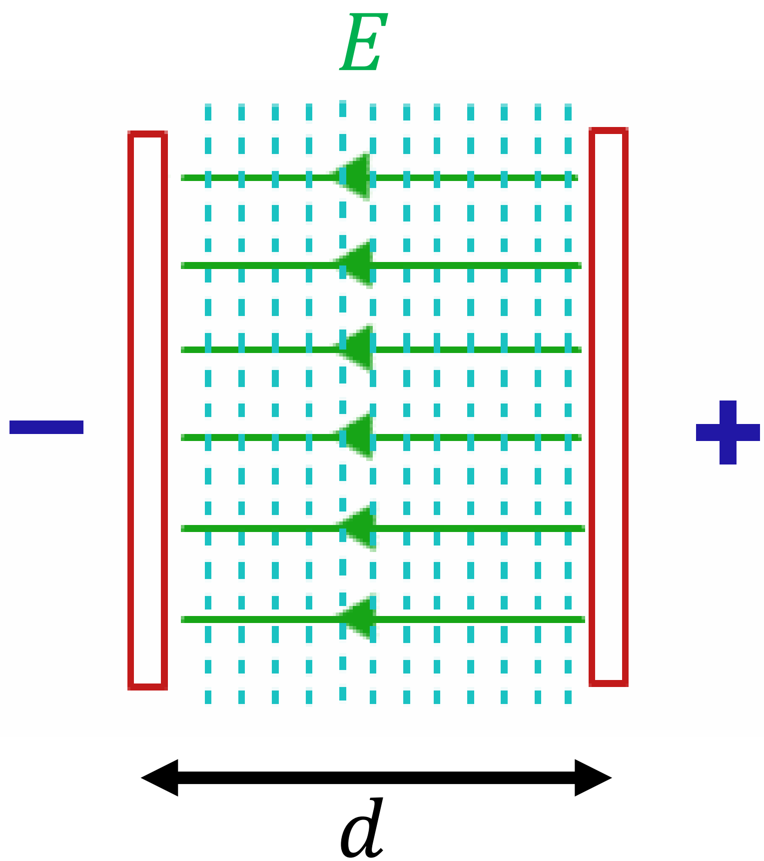
- Electric field is the gradient of potential $E = -\frac{\Delta V}{\Delta x}$



- The dashed lines are called equipotentials (lines of constant V)
- Electric field lines are perpendicular to equipotentials
- It takes no work to move a charge along an equipotential (work done = $dW = \vec{F}.\overrightarrow{dx} = q\vec{E}.\overrightarrow{dx} = 0$)

Electric potential

- Summary for two plates at potential difference V



- Electric field is the potential gradient

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

- Work W to move charge q from –ve to +ve plate

$$W = q\,V$$

Link to potential energy

- The electric potential difference ΔV between two points is the work needed to move 1 C of charge between those points

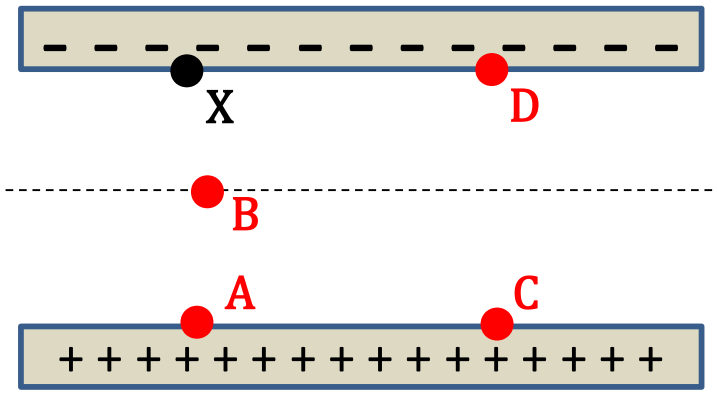
$$W = q \times \Delta V$$

- This work is also equal to the potential energy difference ΔU between those points

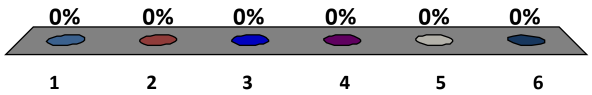
$$\Delta U = q \times \Delta V$$

- Potential V = potential energy per unit charge U/q

An electron is placed at “X” on the negative plate of a pair of charged parallel plates. For the **maximum work** to be done on it, which point should it be moved to?

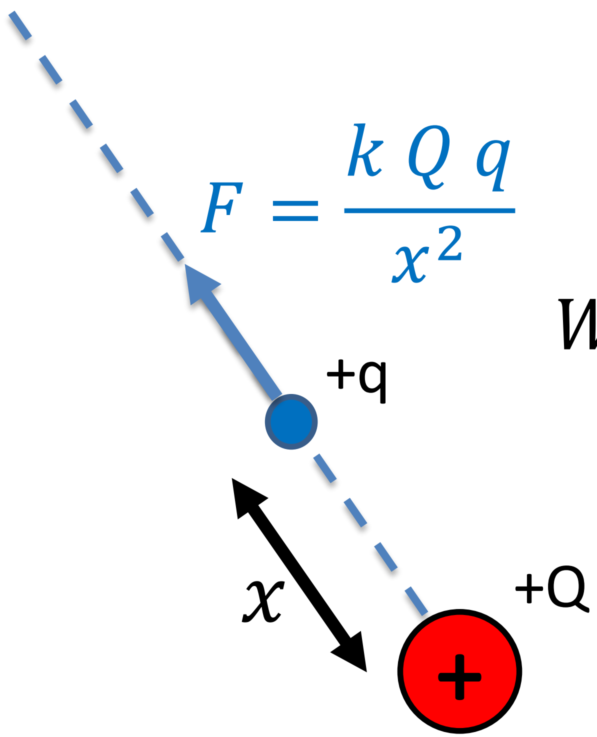


1. A
2. B
3. C
4. D
5. A or C
6. C or D



Electric potential

- What is the electric potential near a charge +Q?



$$F = \frac{k\,Q\,q}{x^2}$$

Work = Force x Distance

Force is varying with distance, need integral!

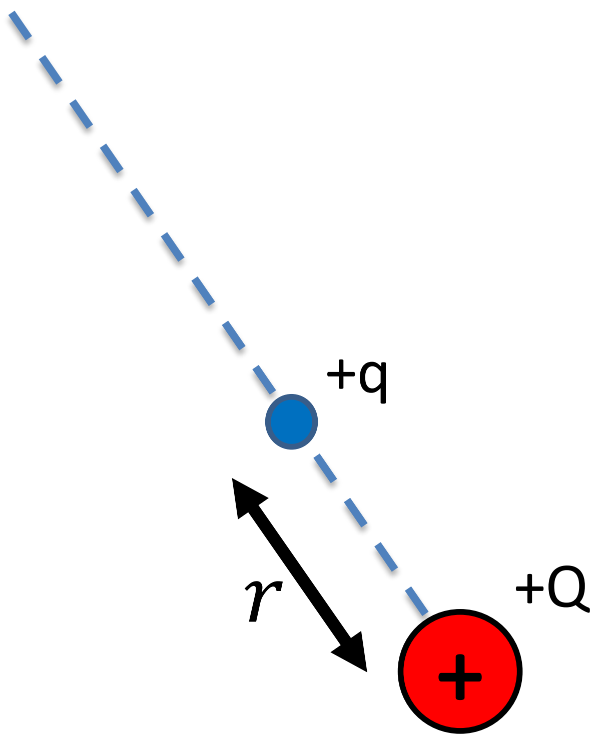
$$W = \int_{\infty}^{r} F\,dx = \int_{\infty}^{r} -\frac{k\,Q\,q}{x^2}\,dx = \frac{k\,Q\,q}{r}$$

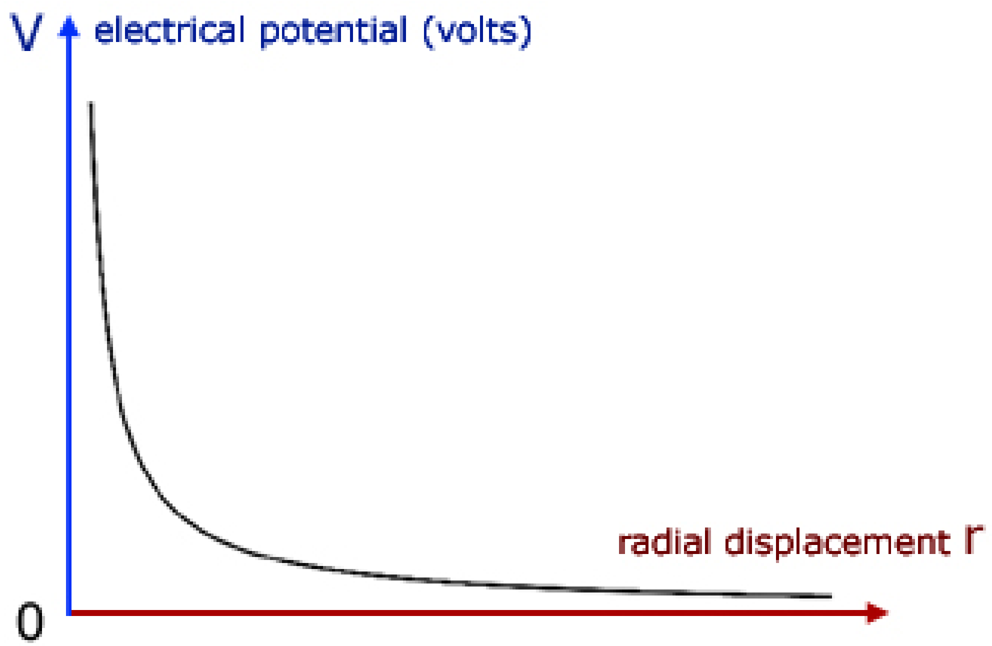
Potential energy $U = \frac{k\,Q\,q}{r}$

Electric potential $V = \frac{U}{q} = \frac{k\,Q}{r}$

Electric potential

- What is the electric potential near a charge +Q?





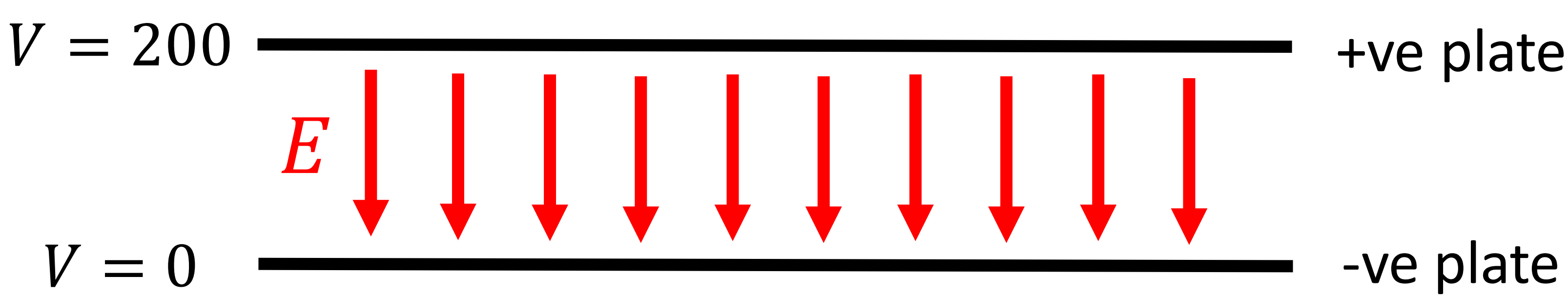
Electric potential $V = \frac{k\,Q}{r}$

Electric potential

<u>Exercise:</u> a potential difference of 200 V is applied across a pair of parallel plates 0.012 m apart. (a) calculate E and draw its direction between the plates.

The electric field is the gradient in potential

$$E = \frac{\Delta V}{\Delta x} = \frac{200}{0.012} = 1.7 \times 10^4\ V\,m^{-1}\ [or\ N\,C^{-1}]$$

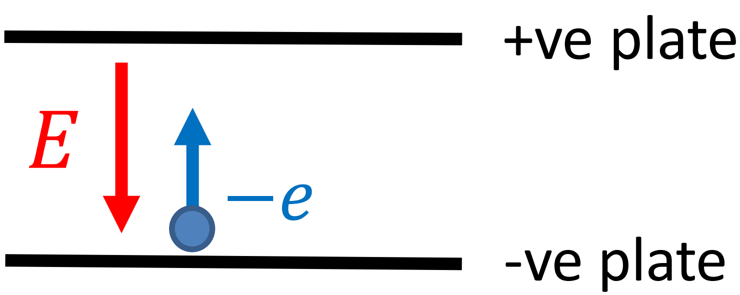


Electric potential

Exercise: a potential difference of 200 V is applied across a pair of parallel plates 0.012 m apart. (b) an electron is placed between the plates, next to the negative plate. Calculate the force on the electron, the acceleration of the electron, and the time it takes to reach the other plate.

Force $F = qE \; = (-1.6 \times 10^{-19}) \times (1.7 \times 10^{4}) \; = -2.7 \times 10^{-15}\, N$

$F = ma$ Acceleration $a = \frac{F}{m} = \frac{2.7 \times 10^{-15}}{9.1 \times 10^{-31}} = 3.0 \times 10^{15}\, m\, s^{-2}$



$d = \frac{1}{2} a t^2$ Time $t = \sqrt{\frac{2d}{a}}$

$t = \sqrt{\frac{2 \times 0.012}{3.0 \times 10^{15}}} = 2.8 \times 10^{-9}\, s$

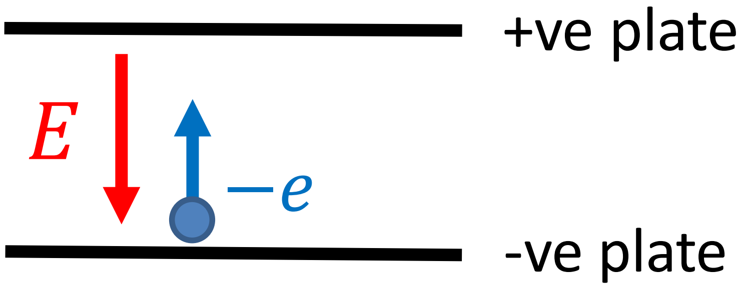
$e = 1.6 \text{ x } 10^{-19}$ C; $m_e = 9.1 \text{ x } 10^{-31}$ kg

Electric potential

<u>Exercise:</u> a potential difference of 200 V is applied across a pair of parallel plates 0.012 m apart. (c) calculate the work done on the electron as it travels between the plates.

The potential difference is the work done on 1C charge

Work $W = qV \quad = (1.6 \times 10^{-19}) \times 200 \quad = 3.2 \times 10^{-17}\, J$



$e = 1.6 \times 10^{-19}$ C; $m_e = 9.1 \times 10^{-31}$ kg

Chapter 22 summary

- Electric potential difference V is the work done when moving unit charge: $W = qV$
- The electric potential energy is therefore also given by: $U = qV$
- The electric field is the gradient of the potential: $E = -\Delta V / \Delta x$
- Charges feel a force from high electric potential to low potential