DEVIL PHYSICS

THE BADDEST CLASS ON CAMPUS

IB PHYSICS

Faraday Cage Experiment

TSOKOS LESSON 5-1
ELECTRIC FIELDS

Introductory Video

[Electrical Charge and Potential]

Essential Idea:

- When charges move an electric current is created.

Nature Of Science:

- Modelling:
  - Electrical theory demonstrates the scientific thought involved in the development of a microscopic model (behaviour of charge carriers) from macroscopic observation.
  - The historical development and refinement of these scientific ideas when the microscopic properties were unknown and unobservable is testament to the deep thinking shown by the scientists of the time.

International-Mindedness:

- Electricity and its benefits have an unparalleled power to transform society

Theory Of Knowledge:

- Early scientists identified positive charges as the charge carriers in metals; however, the discovery of the electron led to the introduction of “conventional” current direction.
- Was this a suitable solution to a major shift in thinking?
- What role do paradigm shifts play in the progression of scientific knowledge?

Understandings:

- Charge
- Electric field
- Coulomb’s law
- Electric current
- Direct current (dc)
- Potential difference

Applications And Skills:

- Identifying two forms of charge and the direction of the forces between them
- Solving problems involving electric fields and Coulomb’s law

Applications And Skills:

- Calculating work done in an electric field in both joules and electronvolts
- Identifying sign and nature of charge carriers in a metal

Applications And Skills:

- Identifying drift speed of charge carriers
- Solving problems using the drift speed equation
- Solving problems involving current, potential difference and charge

Guidance:

- Students will be expected to apply Coulomb’s law for a range of permittivity values

Data Booklet Reference:

$$I = \frac{\Delta q}{\Delta t}$$

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

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

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

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

$$I = nAvq$$

Utilization:

- Transferring energy from one place to another (see Chemistry option C and Physics topic 11)
- Impact on the environment from electricity generation (see Physics topic 8 and Chemistry option sub-topic C2)
- The comparison between the treatment of electric fields and gravitational fields (see Physics topic 10)

Aims:

- Aim 2: electrical theory lies at the heart of much modern science and engineering
- Aim 3: advances in electrical theory have brought immense change to all societies

Aims:

- Aim 6: experiments could include (but are not limited to): demonstrations showing the effect of an electric field (eg. using semolina); simulations involving the placement of one or more point charges and determining the resultant field

Aims:

- Aim 7: use of computer simulations would enable students to measure microscopic interactions that are typically very difficult in a school laboratory situation

Electric Charge

- Electricity is the study of electric charge
- Two kinds of charges: positive and negative
  - Positive charge resides on protons
  - Negative charge resides on electrons

Electric Charge

- Electrons
  - Electrons are lighter, move easier and reside on the outer shell of the atom
  - Electrons can be stripped from an atom leaving a positively charged ion
  - Thus the flow of electricity in solid bodies is due to the motion of electrons
    - In liquids and gases, positive ions can also transport charge
  - Electrons carry the smallest unit of charge of any free particle

Electric Charge

- It is quantized – the charge on a body is always an integral multiple of the charge of one electron
  - The charge on one electron (-e, called the *elemental charge*) is **$1.6\text{x}10^{-19}$**C (Coulomb, charge carried by 1 ampere)
  - The energy carried by 1 electron is called 1 electron volt (eV) is equal to **$1.6\text{x}10^{-19}$** J
  - Mucho Importante: **$1.6\text{x}10^{-19}$** is both the value of the elemental charge (C) AND a conversion factor (J/ev)

Electric Charge

- **All materials are classified as either conductors or insulators (unless it is a semi-conductor)**
  - **Conductors have many free electrons so electricity flows freely through them**
  - **Insulators, well, don’t**
  - **Semiconductors have properties of both**
    - **Tend to have greater conductive properties under certain circumstances**

Electric Charge

- Electric charge is conserved like total energy – cannot be created or destroyed
  - Electrons are not destroyed
  - Charge is merely balanced
- The total charge of an isolated system cannot change

Tolman-Stewart Experiment

- When a metal conductor was accelerated, a negative charge built up on the trailing edge
- The inertia of free and loose-living electrons cause them to move to the back and a net positive charge at the front
- Proof that electrons are the *charge-carriers*

Electric Charge

- *If two identical conductors have charges of 7μC and -12μC respectively. If the two are allowed to touch and then separated, what will be the charge on each?*

Electric Charge

- *If two identical conductors have charges of 7μC and -12μC respectively. If the two are allowed to touch and then separated, what will be the charge on each?*
- *When the two spheres touch, the net charge will be -5μC. When they separate, each conductor will take half the charge, so each one will have a charge of -2.5μC.*

Electric Force

- **Observation shows that there is a force between electric charges**
  - **Like charges repel each other**
  - **Opposite charges attract each other**
  - **Magnitude of the force is directly proportional to the size of the charge, AND inversely proportional to the square of the distance between them**

Coulomb's Law

- **Magnitude of the force between charges is directly proportional to the size of the charge, AND inversely proportional to the square of the distance between them**

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Coulomb's Law

- ε_o is the electric permittivity of a vacuum
- ε_o = 8.85x10^{-12} C^2 N^{-1} m^{-2}
- k = 8.99x10^9 N m^2 C^{-2}
- *Notice the similarity to Newton's Law of Universal Gravitation?*

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$$

$$\varepsilon_0 = 8.85x10^{-12}\, C^2 / N \cdot m^2$$

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

$$k = 8.99x10^9\, N \cdot m^2 / C^2$$

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

Coulomb’s Law

- Sample Problem

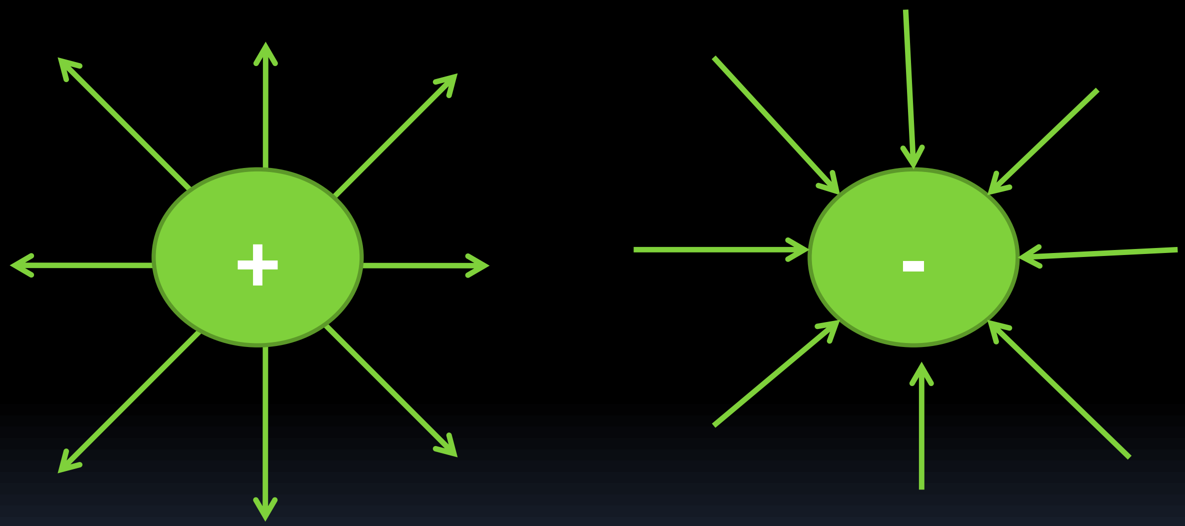
Introductory Video: Electric Fields and Potential

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

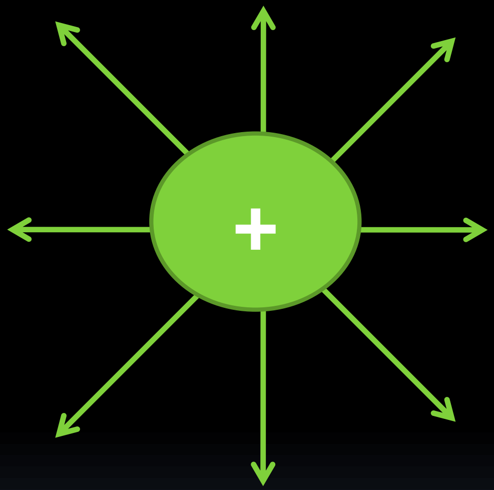
- The field does not "exist" unless shown to exist by a charge
- We use a ***small positive test charge***, q, to determine if a field exists – bring the test charge close and if it experiences a force, then a field exists

Electric Field

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

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

$$F = qE$$



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**

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

$$F = qE$$

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

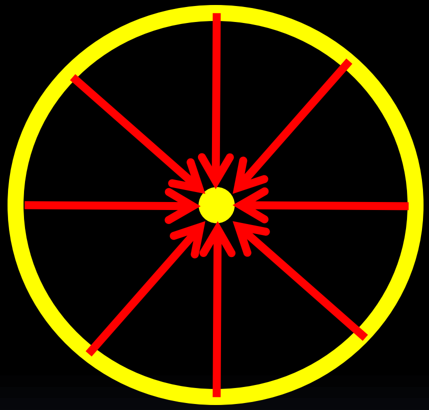
$$qE = k\frac{Q_1 q}{r^2}$$

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

Electric Field

- Likewise, the charge on the ***surface*** of a spherical conductor is given by

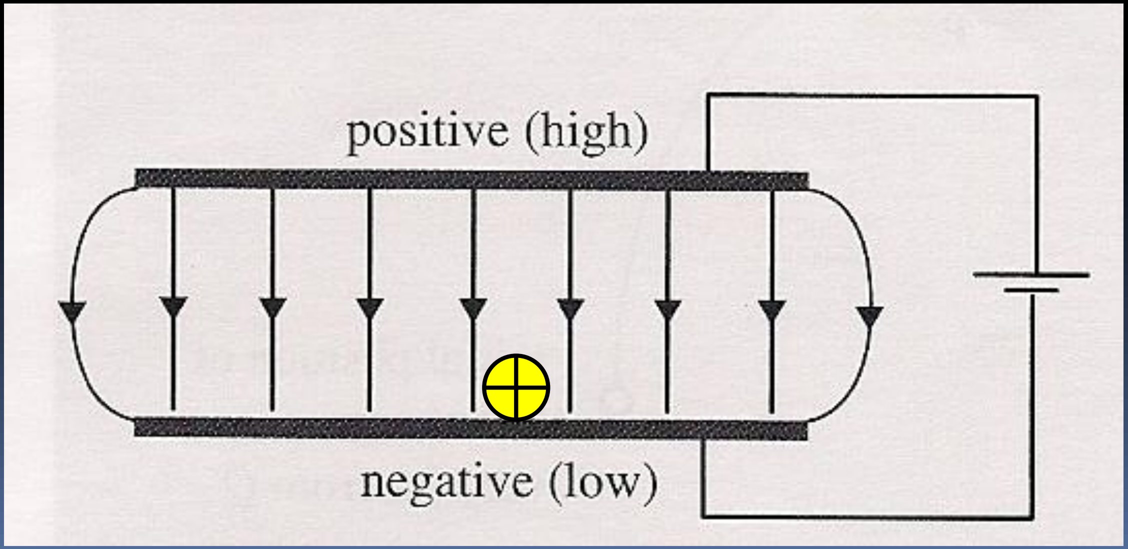
$$E = k\frac{Q}{R^2}$$



where R is the radius of the sphere. *Inside the conductor the field is zero*

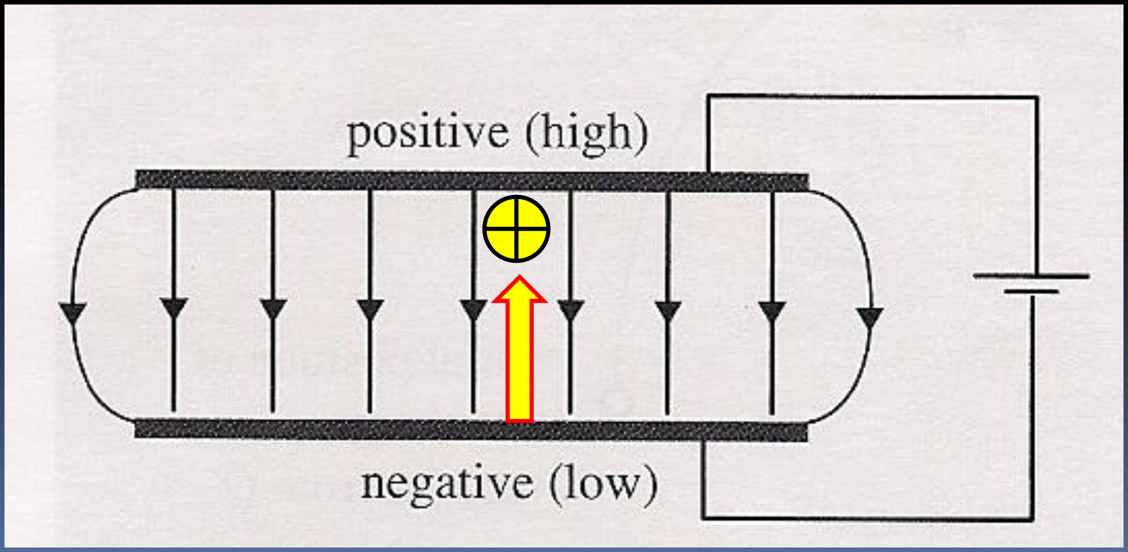
Electric Potential

- 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

- 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

- "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

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

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

$$qV = W = PE$$

Electric Potential

- The unit of potential is:

  $$1V = 1J/1C$$

- The potential energy, U, is:

  $$U = qV$$

- The unit of potential energy is:

  $$(1C) \times (1J/1C) = 1J$$

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

$$W = \Delta U$$

$$W = U_B - U_A$$

$$W = qV_B - qV_A$$

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

Potential Difference

- *Whenever there is a potential difference between two objects, there is an electric field between those objects.*

$$W = \Delta U$$

$$W = U_B - U_A$$

$$W = qV_B - qV_A$$

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

Electronvolt

- Atomic physics deals with extremely small amounts of energy where the Joule is not really appropriate
- The electronvolt, *eV*, is equal to the work done when the charge on one electron is moved across a potential difference of 1 volt

$$W = qV$$

$$1eV = \left(1.6x10^{-19}C\right)\left(1V\right)$$

$$1eV = 1.6x10^{-19}J$$

Electronvolt

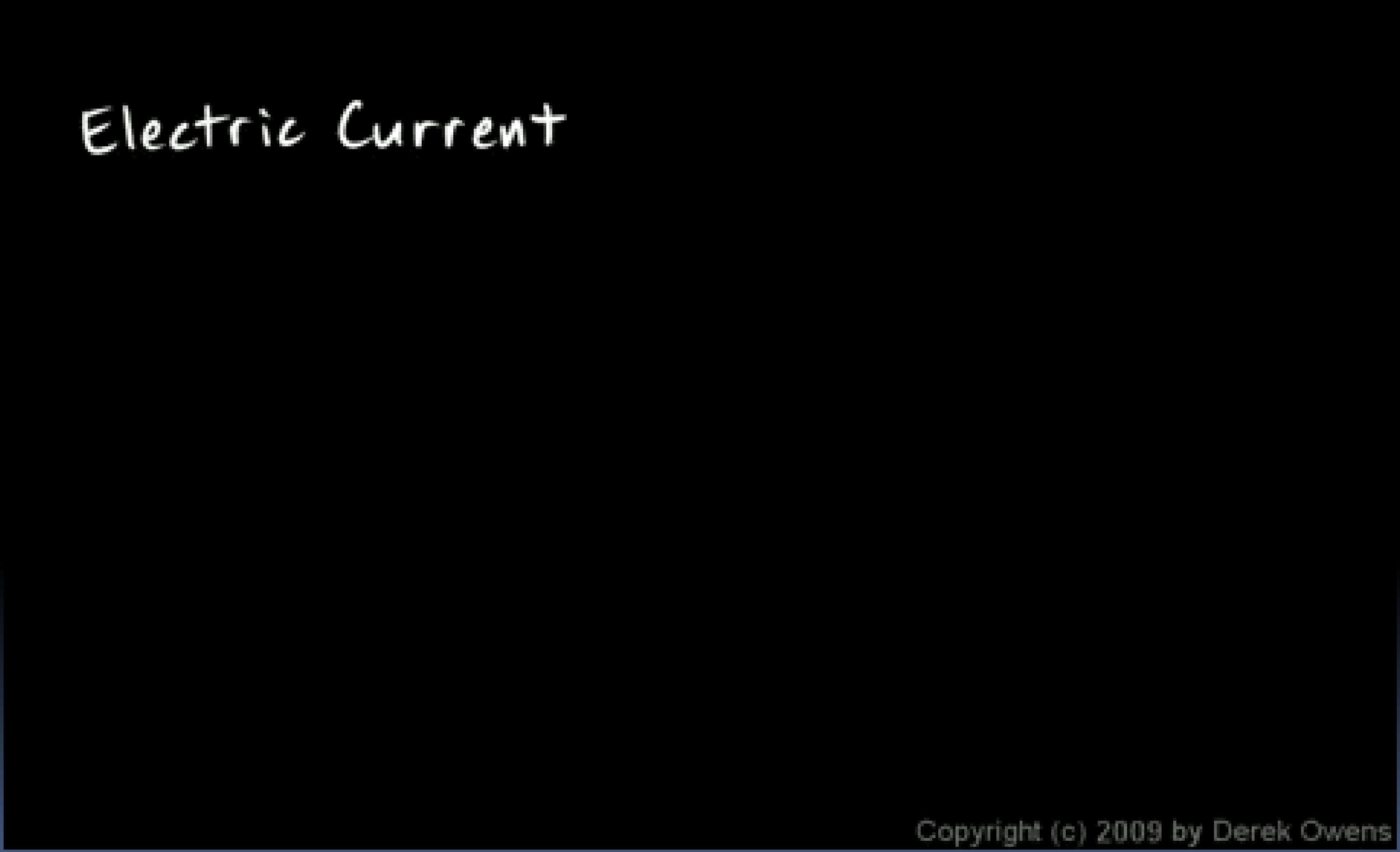
$$W = qV$$

$$1eV = \left(1.6x10^{-19}C\right)\left(1V\right)$$

$$1eV = 1.6x10^{-19}J$$

- Example:
  - To move an object with a charge equal to 2 electrons across a potential difference of 9V, the work is equal to 18 eV

Video: Electric Current



Electric Current

- Electric current is the amount of charge that moves through the cross-sectional area of a wire per unit time

$$I = \frac{\Delta q}{\Delta t}$$

- The unit for current is the ampere (A) and is equal to 1C/s

Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- **EXAMPLE: Light falling on a metallic surface causes the surface to emit 2.2×10^{15} electrons per second. What is the current leaving the surface?**

Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- EXAMPLE: Light falling on a metallic surface causes the surface to emit $2.2x10^{15}$ electrons per second. What is the current leaving the surface?
- **ANSWER:**

$$2.2x10^{15}\,\frac{electrons}{second}\,x1.6x10^{-19}\,\frac{Coulombs}{electron}$$

$$3.5x10^{-4}\,C/s\,(A)$$

Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- In an uncharged conductor, the electrons move *randomly* at speeds on the order of 10^5 m/s
- The presence of an electric field in a conductor causes the electrons to accelerate in a direction opposite to the electric field.
- This ordering of the electron motion is what causes current.

Electric Current

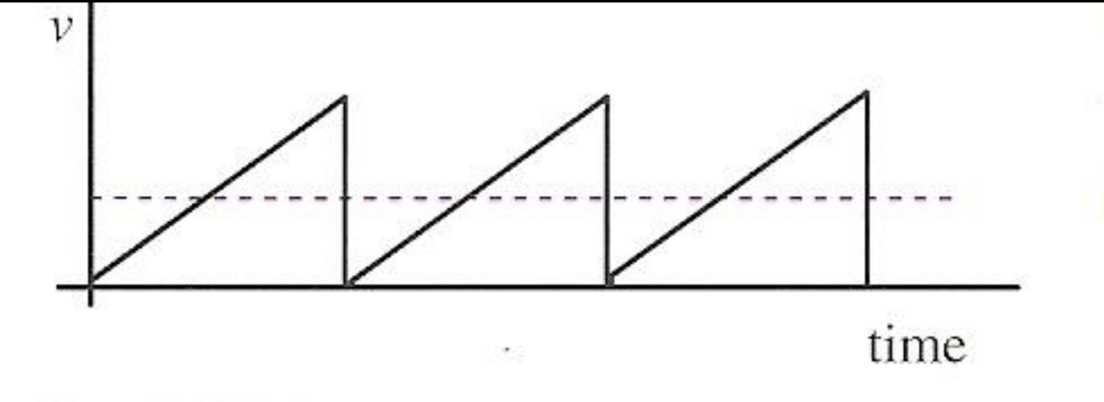
$$I = \frac{\Delta Q}{\Delta t}$$

- As the electrons move, they collide with atoms of the material and impart some of their energy to those atoms
  - This causes the atoms to increase the amplitude of their vibrations about their equilibrium position
  - These increased vibrations show up as heat
  - This is how we get toast

Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- **After the collision, the electrons are again accelerated by the electric field**
- **The graph below represents this pattern. The dotted line represents the average, or *drift velocity* of the electron**



Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- For a typical metal, the drift velocity is on the order of 6×10^{-4} m/s
- With this velocity, how long should it take for the lights to come on when you flip the switch?

Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- For a typical metal, the drift velocity is on the order of $6x10^{-4}$ m/s
- With this velocity, how long should it take for the lights to come on when you flip the switch?

$$(7m)\left(\frac{1}{6x10^{-4}}\right) = 11{,}667s = 3hrs, 15\min$$

- So why do the lights come on instantaneously?

Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- When an electric field is applied, every free electron in the conductor is energized – like the difference between opening a valve at the end of a pipe that is full of water versus opening a valve at the beginning of a pipe that is empty.

Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- By convention, *the direction of current is the opposite direction of the flow of electrons*

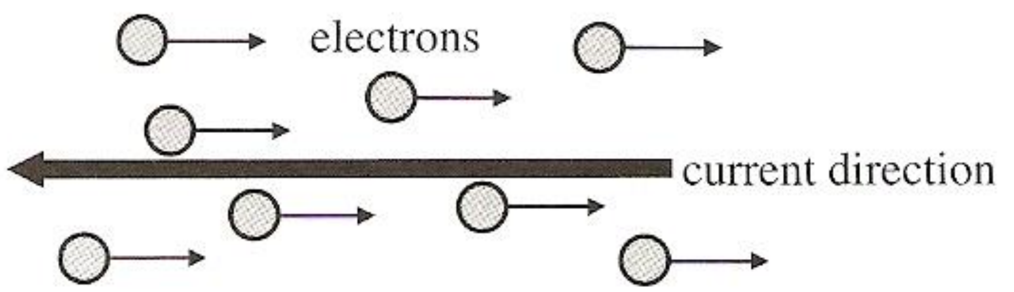


Figure 4.3 The direction of the current is taken to be opposite to the actual electron motion.

  - Current flows from positive to negative
  - Electrons move from negative to positive

Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- Special Cases:
  - When a conductor is heated, it emits electrons through a process called *thermionic emission* which creates a current, or increases conductivity
  - When light hits a metallic surface, electrons are emitted which creates a current – photoelectric effect

Understandings:

- Charge
- Electric field
- Coulomb’s law
- Electric current
- Direct current (dc)
- Potential difference

Aims:

- Aim 2: electrical theory lies at the heart of much modern science and engineering
- Aim 3: advances in electrical theory have brought immense change to all societies

Aims:

- Aim 6: experiments could include (but are not limited to): demonstrations showing the effect of an electric field (eg. using semolina); simulations involving the placement of one or more point charges and determining the resultant field

Aims:

- Aim 7: use of computer simulations would enable students to measure microscopic interactions that are typically very difficult in a school laboratory situation

Applications And Skills:

- Identifying two forms of charge and the direction of the forces between them
- Solving problems involving electric fields and Coulomb's law

Applications And Skills:

- Calculating work done in an electric field in both joules and electronvolts
- Identifying sign and nature of charge carriers in a metal

Applications And Skills:

- Identifying drift speed of charge carriers
- Solving problems using the drift speed equation
- Solving problems involving current, potential difference and charge

Essential Idea:

- When charges move an electric current is created.

QUESTIONS?

Homework

- Lsn 5-1, #1-14

STOPPED HERE ON 4/8/15