Current of Electricity

(For ALL H1 and H2 Physics Students)
Home Based Learning
Please log-in to AskNLearn individually

Suggested Time Allocation
H1 Students
1.5 hr – Lecture notes and tutorial
0.5 hr – Online forum and assignment

H2 Students
3.0 hr – Lecture notes and tutorial
1.0 hr – Online forum and assignment

Optional – Self-explore Yenka Physics

Content

- Electric current
- Potential difference
- Resistance and resistivity
- Sources of electromotive force

Learning Outcomes

Candidates should be able to:

(a) show an understanding that electric current is the rate of flow of charged particles.

(b) define charge and the coulomb.

(c) recall and solve problems using the equation $Q = It$.

(d) define potential difference and the volt.

(e) recall and solve problems using $V = W/Q$.

(f) recall and solve problems using $P = VI$, $P = I^2R$.

(g) define resistance and the ohm.

(h) recall and solve problems using $V = IR$.

(i) sketch and explain the I-V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp.

(j) sketch the temperature characteristic of a thermistor.

(k) recall and solve problems using $R = \rho l/A$.

(l) define e.m.f. in terms of the energy transferred by a source in driving unit charge round a complete circuit.

(m) distinguish between e.m.f. and p.d in terms of energy considerations.

(n) show an understanding of the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

Instructions for HBL
Learning Outcomes covered for H1 Physics includes (a) – (e) and (j) – (m) and H2 Physics includes the whole topic from (a) – (n). The requirement for Current of Electricity is the same for H1 and H2 Physics hence the notes is the same. Participation in online forum, quiz is **compulsory.**

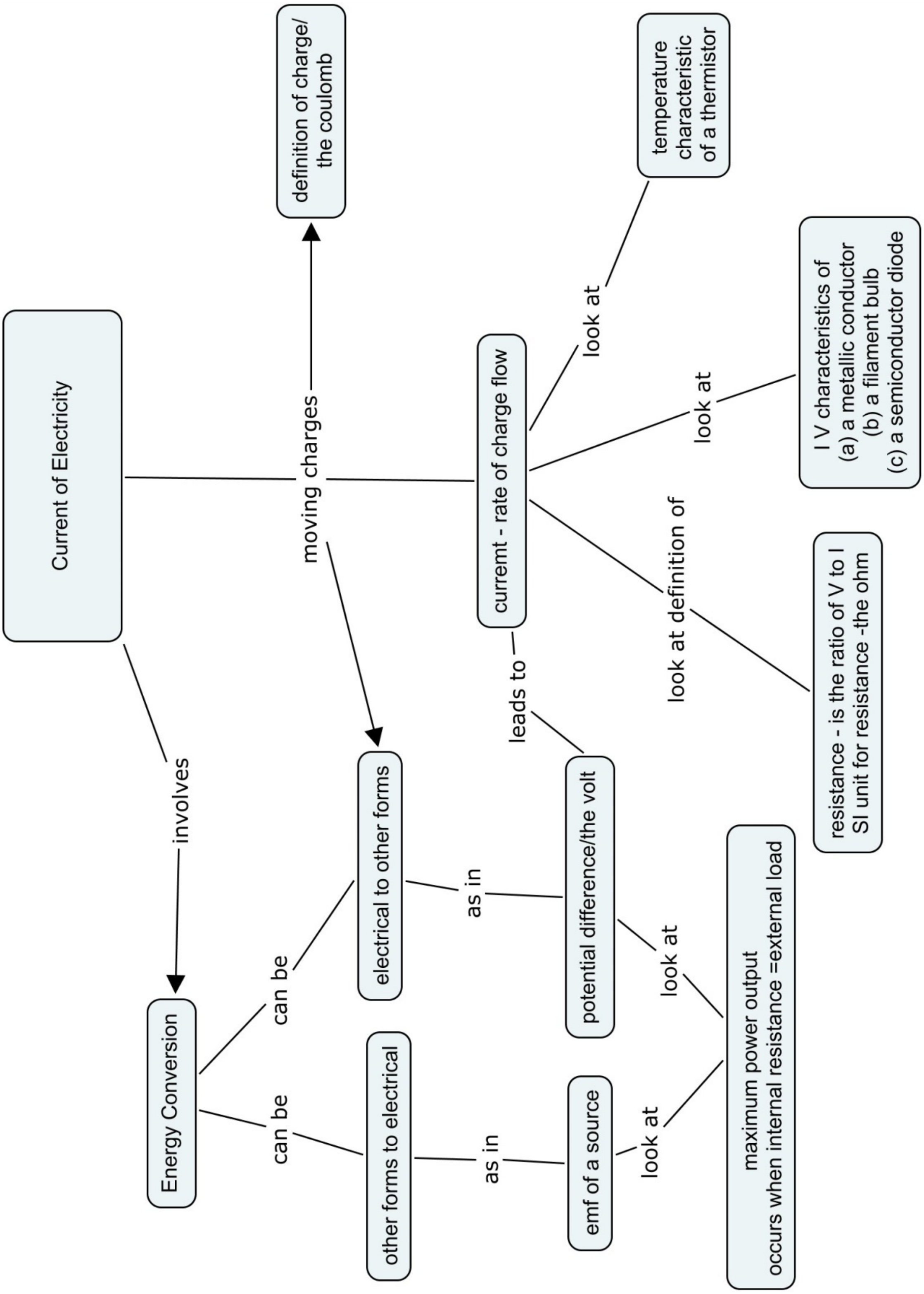
H1 Students
This HBL is a revision from your Junior High Physics hence you should spend less than an hour on the notes to read up to page 11 and another 45 min to complete the tutorial, online discussion and online assessment (part 1)

H2 Students
Learning outcome (n), internal resistance of a source of e.m.f., is new content not learned in Junior High, hence you should spend more time going through page 12-14 of your notes and go through the rest of the materials on AskNLearn.

CONTENT

H1 students, your HBL is only 2 hours, you just need to learn up to 3.4. The rest will be discussed in class next year. H2 students are to complete this whole set of notes

Concept Map



Current of Electricity
moving charges
definition of charge/ the coulomb
curremt - rate of charge flow
look at
temperature characteristic of a thermistor
look at
I V characteristics of (a) a metallic conductor (b) a filament bulb (c) a semiconductor diode
look at definition of
resistance - is the ratio of V to I SI unit for resistance -the ohm
leads to
potential difference/the volt
involves
Energy Conversion
can be
electrical to other forms
can be
other forms to electrical
as in
as in
emf of a source
look at
look at
maximum power output occurs when internal resistance =external load

Learning Objective:
Candidates should be able to:
(a) show an understanding that electric current is the rate of flow of charged particles.
(b) define charge and the coulomb.
(c) recall and solve problems using the equation $Q = It$.

1.0 Flow of Charged Particles

1.1 Charge and the Coulomb

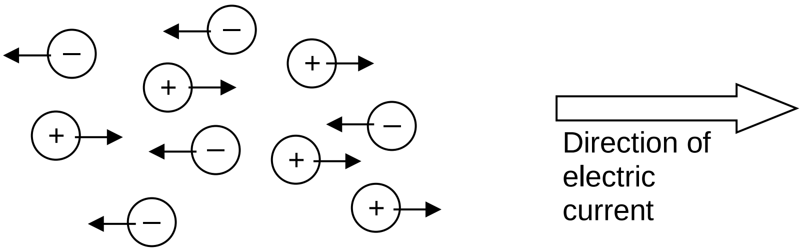
Charge is a property of some elementary particles (particles of matter which cannot be subdivided into smaller matter) that gives rise to interactions between them and consequently to the host of material phenomena described as electrical.

Charge occurs in 2 forms, conventionally described as positive and negative. The natural unit of negative charge *e* (1.60×10^{-19} C) is the charge on an electron, which is equal but opposite in effect to the positive charge on the proton.

The SI unit of charge is the *coulomb* (C) which is defined as <u>*the quantity of electric charge transported through a cross-section of a conductor in one second by an electric current of one ampere*</u>.

1.2 Electric Current

An *electric current*, which is a SI base quantity measured in the SI base unit of *ampere* (A), consists of charges in motion from one region to another. When this motion takes place within a conducting path that forms a closed loop, the path is called an *electric circuit*. In metals, current is due to the flow of electrons which carry negative charges. In semiconductors, gases and electrolytes, current can be attributed to both positive and negative charges. It should be noted, however, that the direction of the current is, by convention, the direction that positive charges move.



At room-temperature, ordinary metals such as copper or iron have electrons which are free to move within the physical constraints of the material. These free electrons move randomly in all directions, somewhat like the molecules of a gas but with much greater speeds (of the order of 10^6 m s^{-1}). Considering a cross-section of the material, the rate at which electrons pass the cross-section in one direction is equal to the rate at which they cross in the other direction. Hence, the net flow of charge through the cross-section is zero.

If the ends of the conducting wire are connected to form a loop, all points on the loop are at the same electric potential and hence the electric field is zero within and at the surface of the conductor. Because the electric field is zero, there is no net transport of charge through the wire and therefore there is no current.

However if the ends of the conducting wire are connected to a battery, all the points on the loop are not at the same potential. The battery sets up a potential difference between the ends of the loop, creating an electric field within the wire. The electric field exerts forces on the conduction electrons in the wire, causing them to move in the wire, thus creating a net movement of electric charges.

Electric current flowing through a cross-section of a conductor is defined as the rate of flow of charges through it. Hence, the instantaneous current passing through a cross section of the conductor at a given time is given by

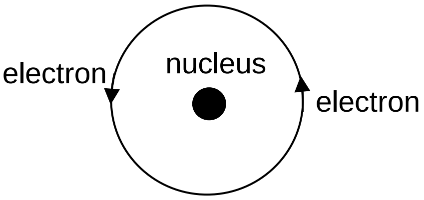
$$I = \frac{dQ}{dt}$$

Hence, if the electric current *I* is steady, then the total amount of charge *Q* which flows past a point in a time duration *t* would be given by

$$\boxed{\boldsymbol{Q = It}}$$

Worked Example 1

The diagram on the right shows a model of an atom in which two electrons move round a nucleus in a circular orbit. The electrons complete one full orbit in 1.0 x 10^{-10} s. What is the current caused by the motion of the electrons in the orbit?



$$\boldsymbol{I = \frac{Q}{t}}$$
$$\boldsymbol{= \frac{2\left(1.6 \times 10^{-19}\right)}{1.0 \times 10^{-10}}}$$
$$\boldsymbol{= 3.2 \times 10^{-9}\,\mathrm{A}}$$

Worked Example 2

A high potential is applied between the electrodes of a discharge tube so that the gas is ionized. Electrons and positive ions move towards the positive and negative electrodes respectively. In each second, 5 x 10^{18} electrons and 2 x 10^{18} singly charged positive ions pass a cross-section of the tube. Determine the current flowing in the discharge tube.

The movement of both electrons and positive ions contribute to electric current.

$$\begin{aligned} I &= \frac{Q}{t} \\ &= \frac{(5 \times 10^{18} + 2 \times 10^{18})(1.6 \times 10^{-19})}{1} \\ &= 1.12\text{A} \end{aligned}$$

Learning Objective:

Candidates should be able to:

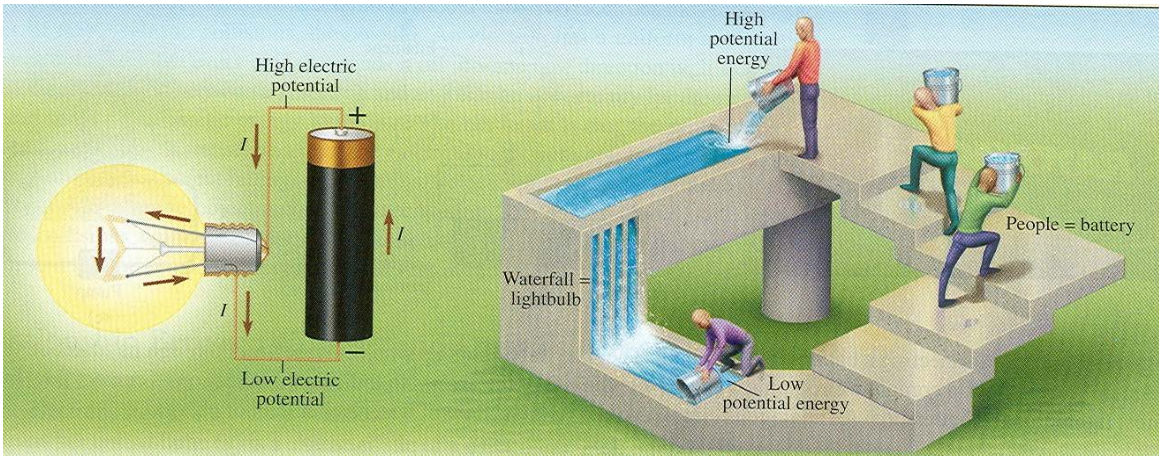
(d) define potential difference and the volt.

(e) recall and solve problems using *V* = *W/Q*.

(l) define e.m.f. in terms of the energy transferred by a source in driving unit charge round a complete circuit.

(m) distinguish between e.m.f. and p.d in terms of energy considerations.

2.0 Potential Difference and Electromotive Force



Consider the analogy of the human powered waterfall to a simple lighting circuit.

The people act as a pump, taking water from the place where its potential energy is lowest and doing the necessary work to carry it uphill to the place where its potential energy is highest. The water then runs downhill, encountering resistance to its flow along the way before returning to the point with the lowest potential energy.

With the flow of water representing the flow of positive charge in an electric circuit, a battery plays a role analogous to the people who carry buckets of water; a battery takes positive charges from the place where the electric potential is lowest (negative terminal of the battery) and does the necessary work to move it to the place where the electric potential is the highest (positive terminal). Then the charge flows through an electrical device (i.e. light bulb) which offers resistance to the flow of current before returning to the negative terminal of the battery.

Just as water would flow naturally from a place with higher potential to a lower potential, electric current flows from a point of higher potential in an electric circuit to a point of lower potential.

2.1 Electric Potential Difference

When a current passes through an electrical device, electrical energy is converted into other forms of energy (i.e. heat in a resistance wire, light emitted by a lamp or mechanical energy in a motor). The amount of electrical energy converted per unit charge flow is called the *electric potential difference*.

Hence, the electric potential difference between two points in a circuit may be defined as <u>*the amount of electrical energy transformed per unit charge to some other forms of energy when the charge passes from one point to the other*</u>.

Mathematically, the electric potential difference *V* between 2 points in a circuit is given by

$$\boxed{\boldsymbol{V = \frac{W}{Q}}}$$

where *W* is the energy transformed from electrical to non-electrical energy when a charge of *Q* flows in that part of the circuit.

2.2 Electromotive Force

In order to maintain an electric current in an electrical circuit, a potential difference across the ends of the entire circuit is required. To achieve this, the ends of the electrical circuit may be connected to the opposite terminals of a battery. This potential difference which is maintained by the battery is known the electromotive force or the e.m.f. of the battery. The e.m.f. is a measure of the work done by the battery per unit charge.

Hence, the e.m.f. of a source can be defined as <u>*the work done in transforming non-electrical energy into electrical energy per unit charge passing through the terminals of the source*</u>.

2.3 Differences between Electromotive Force and Potential Difference

Electromotive Force (e.m.f)	**Potential Difference (p.d.)**
Refers only to source	Refers to any two points in an electrical circuit
Considers the amount of non-electrical energy converted into electrical energy per unit charge passing through the terminals of the cell (source).	Considers the amount of electrical energy converted to other forms of energy per unit charge passing from one point to the other.
It is a source of energy and it will exist whether or not a current is flowing in the circuit.	It can only exist if current is flowing in the electrical circuit.

2.4 The Volt

The SI unit of potential difference (and e.m.f.) is the *volt* (V) which may be defined as *<u>the potential difference between two points in a circuit where one joule of electrical energy is converted to other forms of energy when one coulomb of charge passes from one point to the other</u>*.

Learning Objective:
Candidates should be able to:
(g) define resistance and the ohm.
(h) recall and solve problems using $V = IR$.
(k) recall and solve problems using $R = \rho l/A$.
(i) sketch and explain the *I-V* characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp.
(j) sketch the temperature characteristic of a thermistor.

3.0 Resistance

The *resistance* of a conductor is a measure of its opposition to the flow of current through itself. It is the property of a given conductor which limits the current flow.

The resistance *R* of a conductor is *<u>the ratio of the potential difference across the conductor to the current flowing through the conductor</u>*.

Mathematically: $$\boxed{R = \frac{V}{I}}$$

3.1 The Ohm

The SI unit of resistance is the *ohm* (Ω) which is defined as *the electrical resistance between two points of a conductor through which a steady current of one ampere flows when a constant potential difference of one volt is maintained across it*.

3.2 Ohm's Law

Georg Simon Ohm was the first to study the resistance of different materials systematically. He established experimentally that *the current I in a metallic conductor is proportional to the potential difference V applied to its two ends, provided that the physical conditions (such as temperature, stress of the material etc) remained constant*.

Mathematically: $\boxed{\boldsymbol{I \propto V}}$

Hence, an implicit characteristic of ohmic conductors is that its resistance remains a constant.

Point to Ponder

When comparing Ohm's Law $(I \propto V)$ to the definition of resistance $\left(R = \frac{V}{I}\right)$, it would seem that the 2 relationships are the same. Hence, is the latter just a restatement of the former?

Ohm's Law requires *I* to vary proportionally to *V*, implicitly requiring an *I-V* graph of an ohmic conductor to be a straight line passing through the origin (since when *V* is zero, *I* should be zero as well). However, the definition of resistance simply allows the resistance of any material under any condition(s) to be determined.

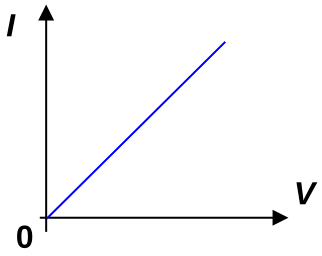
3.3 I-V Characteristics

The *I-V* graph of a material, which is obtained experimentally, allows the resistance of the material to be determined for various values of *V* (or *I*). Why does the resistance of most materials not remain a constant?

When the potential difference or the current across through a material increases, the temperature of the material is likely to increase. When the latter occurs, two main changes occur at the molecular level which affects the resistance of the material:

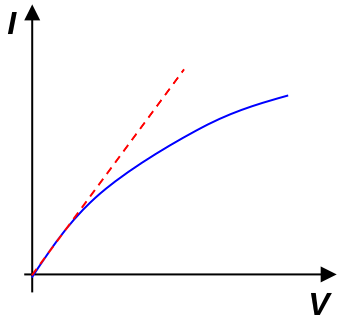
1. the number of free electrons, which act as charge carriers, increases which reduces the resistance of the material.
2. the lattice vibration of the molecular structure increases which increases the resistance of the material.

3.3.1 Metallic Conductor at Constant Temperature



Since the conductor is maintained at constant temperature, number of free electrons is fixed and the rate of atomic vibration remains unchanged. Thus the resistance remains a constant and the conductor is said to be ohmic.

3.3.2 Filament Lamp

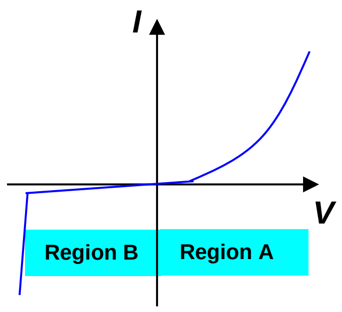


As the *V* increases, *I* increases linearly up to the point where the bulb lights up. At this junction, the temperature increases whereby the conductor behaviour becomes non-linear.

As the temperature increases, the no. of free electrons will not vary significantly but the rate of atomic vibration increases. Since the increase in the rate of atomic vibration predominates over the increase of the number of free electrons, the overall effect is that resistance *R* increases.

Hence, further increase of the *V* causes a less than proportionate increase in the current.

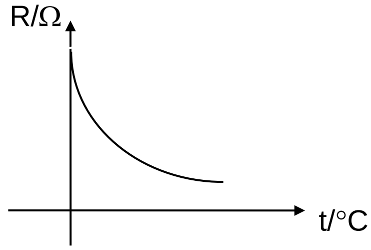
3.3.3 Semi-Conductor Diode



Considering for the forward-biased region (region A) of the I-V graph, as *V* increases, temperature of the diode increases. This increases the number of charge carriers significantly. At the same time, there is also an increase in rate of atomic vibration. However, as the increase in the increase of the number of free electrons predominates over the rate of atomic vibration, the overall effect is that resistance *R* decreases.

Hence, further increases of the *V* causes a more than proportionate increase in the current.

3.3.4 Negative Coefficient Thermistor



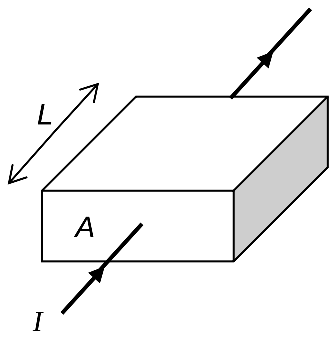
For a negative coefficient thermistor, resistance decreases when temperature increases.

As such, its *I* -*V* characteristic is the same as that for a semiconductor diode for positive values of *V* and *I*.

3.4 Resistivity

The resistance of a conductor depends on its shape and size. Consider the analogy of water flow through a pipe; a longer pipe offers more resistance to water flow than a short pipe while a wider pipe offers less resistance than a narrow pipe. Hence, one would expect electrical resistance to be greater with a longer and thinner conductor.

It is found experimentally that the resistance *R* of any conductor is directly proportional to its length *L* and inversely proportional to its cross-section area *A*.



Mathematically:

$$R \propto \frac{l}{A}$$

$$\boxed{\boldsymbol{R = \frac{\rho l}{A}}}$$

The constant of proportionality ρ is known as the *resistivity*, which depends on the material of the conductor as well as the temperature of the conductor (not the shape or size of the conductor). Metals generally have low resistivity values (of the order of 10^{-13} Ω m) whereas insulators such as rubber have high resistivity values (10^{13} ~ 10^{16} Ω m). Semiconductors have intermediate resistivity values which are highly dependent on temperature; the room-temperature resistivity of a typical semiconductor is several orders of magnitude greater than that of a typical metal.

H1 students may stop after 3.4 for HBL
H2 students must complete the whole set

Worked Example 3

A cylindrical wire of radius *r* and length *l* has a resistance *R*. Another wire made of a similar material has a radius *2r* and *2l*. What is the resistance of the second wire in terms of R?

$R = \frac{\rho l}{A}$		
Resistivity	*ρ*	*ρ*
Length	*l*	*2l*
Cross-sectional Area	*A*	*4A*
Resistance	*R*	*½ R*

Learning Objective:
Candidates should be able to:
(f) recall and solve problems using $P = VI$, $P = I^2R$.
(n) show an understanding of the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

4.0 Electrical Power

Recalling from section 2.1, the relationship between the potential difference *V* across two points and electrical energy *W* that is converted to other forms of energy when a charge *Q* moves through the points is given by

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

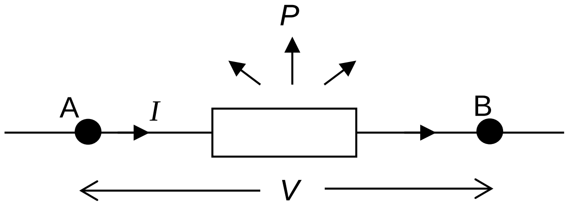
If both the numerator and denominator are divided by time *t*,

$$V = \frac{\frac{W}{t}}{\frac{Q}{t}} = \frac{P}{I}$$

The result is re-arranged to give the familiar relationship

$$\boxed{\boldsymbol{P = IV}}$$

where *P* is the electrical power dissipated by the conductor, I is the current passing through it and *V* is the potential difference across it.



Using the definition of resistance, alternative expressions for power dissipated can be obtained.

$$\begin{aligned} \boldsymbol{P} &= \boldsymbol{IV} \\ &= \boldsymbol{I^2R} \\ &= \frac{\boldsymbol{V^2}}{\boldsymbol{R}} \end{aligned}$$

4.1 Power Rating

The rated power is the rate at which energy is used (power consumption) by a device when the device is operating at the rated potential difference across it.

i.e. For an electrical device rated 100 W, 220 V, it means that when a potential difference of 220 V is applied across the terminals of the device, the device dissipates 100 W of power.

Worked Example 4

The same potential difference is applied across a 30 W light bulb and a 60 W light bulb. These bulbs operate at their rated power only when connected to a 120 V source. Assuming the resistance of the light bulbs remain the same, which one of the following statement is true?

a) The 30 W bulb carries a greater current and has a higher resistance.

b) The 30 W bulb carries a greater current, but the 60 W bulb has a higher resistance.

c) The 30 W bulb has a higher resistance, but the 60 W carries a greater current.

d) The 60W bulb carries a greater current and has a higher resistance

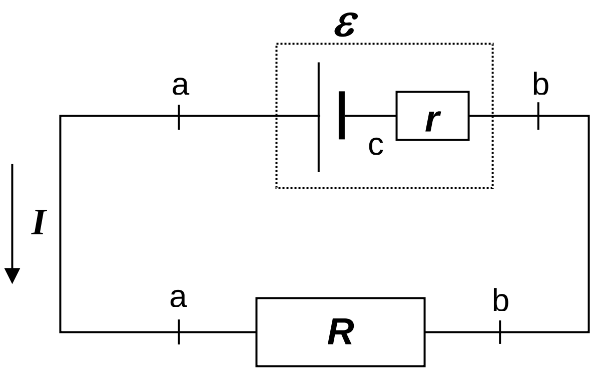
Since $\boldsymbol{P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P}}$, this implies that the resistance of the 30 W bulb is higher. Hence when the same p.d. is applied across both bulbs, the current through the 30 W bulb would be lower.

4.2 Effects of Internal Resistance of a Source

Watch Video on Internal Resistance on AskNLearn now

When a current is drawn from a battery, the potential difference across its terminals (a.k.a. terminal p.d.) is less than its stated e.m.f. This is because the battery itself has some resistance, which is called *internal resistance* (usually designated as *r*), which cannot be removed as it is an inherent part of the source. An e.m.f. source is said to be *ideal* if there is no internal resistance inside the source. However, most practical e.m.f. sources are not ideal.

Considering a practical source with e.m.f. ε and internal resistance r connected in series with an electrical load with resistance R,



By principle of conservation of energy,

Work done by the source of e.m.f. = Total energy dissipated in the circuit

$$P_{gen} = P_R + P_r$$

$$I\varepsilon = IV_R + IV_r$$

$$\varepsilon = V_R + V_r$$

where
- ε is the e.m.f. of the source
- P_R is power dissipated in resistor R
- P_r is power dissipated in internal resistance r
- V_R is p.d. across resistor R
- V_r is p.d. across internal resistance r
- I is the current flowing through both resistances R and r.

(Note that $V_R = V_{ab}$ is also known as terminal p.d. of the cell.)

From the above, it may be observed that not all the total electrical power generated from the e.m.f. source is usefully available to the external load of resistance R; part of the total electrical power is used in overcoming the inherent internal resistance r of the source, which results in power lost as heat in the source (P_r).

In this case, the potential difference across the load R is less than the e.m.f. of the source. The loss voltage appears as the potential difference across the internal resistance r of the source.

Worked Example 5

a) By considering a practical source with e.m.f. ε and internal resistance r connected in series with an electrical device of resistance R, determine

i. an expression for output efficiency of the source, $\eta = \frac{\text{Useful Power Output}}{\text{Total Power Generated}}$

Total power generated $P_{gen} = \mathrm{I^2(R+r)}$
Useful power output $P_{out} = \mathrm{I^2R}$

$$\eta = \frac{\text{Useful Power Output}}{\text{Total Power Generated}}$$
$$= \frac{R}{R+r}$$

ii. the value of R in terms of r such that maximum power is delivered to the device

Current in the circuit,

$$I = \frac{\varepsilon}{R+r}$$

Power output at the load,

$$P_{out} = I^2R$$
$$= \left(\frac{\varepsilon}{R+r}\right)^2 R$$

For maximum power output,

$$\frac{dP_{out}}{dR} = 0$$
$$\varepsilon^2\left[\frac{1}{(R+r)^2} - \frac{2R}{(R+r)^3}\right] = 0$$
$$\varepsilon^2\left[\frac{(R+r)-2R}{(R+r)^3}\right] = 0$$

Hence for maximum power to be delivered to the load, *R* = *r*

b) Using your answers to part (a), discuss the effect on the output efficiency of a source when it is used to operate an electrical device at maximum power.

When the electrical device is operating at maximum power, the output efficiency of the source is 0.5 (50%), implying that half the amount of power generated is lost at the internal resistance of the source.

Definitions List

Charge, Q	A property of some elementary particles (particles of matter that cannot be subdivided into smaller matter) that causes them to exert forces of one another. Charge is given by the integral of electric current with time. $Q = \int I\, dt$. If the rate is constant or if the current is steady, then amount of charge (Q) passing through a given section of a conductor is the **product** of the steady current ***I*** that flows past the section and the time t during which the current flows. $Q = I\, t$
Electric Current	Electric current flowing through a cross-section of a conductor is defined as the rate of flow of charges through it.
Coulomb, C	Defined as the quantity of electric charge transported through a cross-section of a conductor in one second (1 s) by an electric current of one ampere (1 A).
Potential difference (p.d.)	The electric potential difference between two points in a circuit is the amount of electrical energy changed per unit charge to some other forms of energy when the charge passes from one point to the other. Electrical potential difference, V, between two points in a circuit is given by $V = \frac{W}{Q}$ where W is the energy changed when a charge of Q flows in that part of the circuit. **OR** The electric potential difference between two points in a circuit or across a conductor is defined as the rate of transformation of electrical energy to other forms of energy per unit current passing through the two points.
Electromotive Force, ε	The electromotive motive force of a source can be defined as the work done in transforming non-electrical energy into electrical energy per unit charge that passes through it.

Volt (S.I unit for p.d.)	The volt is defined as the potential difference between two points in a circuit where one joule (1 J) of electrical energy is converted to other forms of energy when one coulomb (1 C) of charge passes from one point to the other. **OR** The volt is defined as potential difference between two points on a conductor carrying a current of one ampere (1 A) when the power dissipated is one watt (1 W).
Resistance	The resistance R of a conductor is defined as the ratio $\frac{V}{I}$ where V is the potential difference across the conductor and I is the current flowing in it.
Internal resistance	It is the resistance of the emf source; it is a hindrance to current flow offered by the components within a source; energy is dissipated as heat within the source itself.
Resistivity, ρ	Is an intrinsic characteristic of the material. Unit is ohm meter (Ω m)
Ohm, Ω	Defined as the electric resistance between two points of a conductor through which a steady current of one ampere (1 A) flows when a constant potential difference of one volt (1 V) is maintained across it.
Ohm's Law	Ohm's Law states that a current flowing through a conductor is directly proportional to the potential difference applied across the conductor provided that physical conditions (like temperature, stress etc) remains constant.
Maximum Power Theorem	Maximum power is supplied to the external circuit when the resistance of the external circuit equals to the internal resistance of the cell.

德明政府中学
Dunman High School

Current of Electricity
Tutorial

H2/H1 PHYSICS (2013)

Data :

elementary charge e = 1.60×10^{-19} C

Formulae :

resistors in series $R = R_1 + R_2 + \ldots\ldots$

resistors in parallel $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots\ldots$

H1 students please complete Q1 to Q6 for HBL. H2 students please attempt ALL questions

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1. The current in the electron beam of a computer monitor is 320 μA. How many electrons hit the screen per second? [2.0×10^{15}]

2. A bird stands on a d.c. transmission line carrying 2800 A. The line has 2.5×10^{-5} Ω per metre and the bird's feet are 4.0 cm apart. What is the potential difference between the bird's feet? [2.8×10^{-3} V]

3. A wire of resistance *R* is stretched uniformly until it is twice its original length. Assuming the density of the wire does not change significantly, what is its new resistance in terms of *R*? [4*R*]

4. (a) In a gas, conduction occurs as a result of negative particles flowing one way and positive particles flowing in the opposite direction as illustrated in Figure 1.

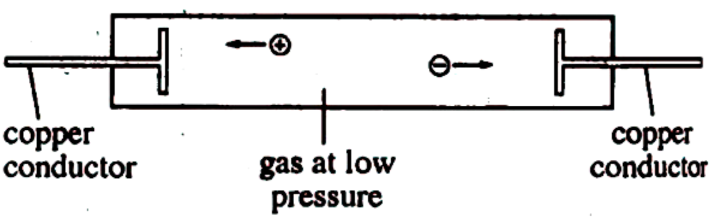


Figure 4

In this case, the copper conductors to the gas carry a current of 0.28 mA. The number of negative particles passing any point in the gas per unit time is 1.56×10^{15} s^{-1} and the charge on each negative particle is -1.60×10^{-19} C. Calculate

(i) the negative charge flowing past any point in the gas per second [2.50×10^{-4} Cs^{-1}]

(ii) the positive charge flowing past any point in the gas per second [3.04×10^{-5} Cs^{-1}]

(iii) the number of positively charged particles passing any point in the gas per second, given that the charge on each positive particle is $+3.2 \times 10^{-19}$ C. [9.50×10^{13} s^{-1}]

(b) By considering the significant figures available, explain why your answers to (a)(ii) and (iii) are unreliable.

5. One element of an electric cooker has an I $\propto$V characteristic as shown Figure 5.

(a) Explain how the characteristic shows that the resistance of the element increases with potential difference.

(b) Explain in terms of the movement of charged particles why the resistance increases with potential difference.

(c) Use the graph to estimate the potential difference which should be applied to the element if it is to have a resistance of 30Ω. [225 V]

(d) What will be the current in the element when it has a resistance of 30Ω. [7.5A]

(e) What will be the power of the element when it has a resistance of 30Ω. [1690W]

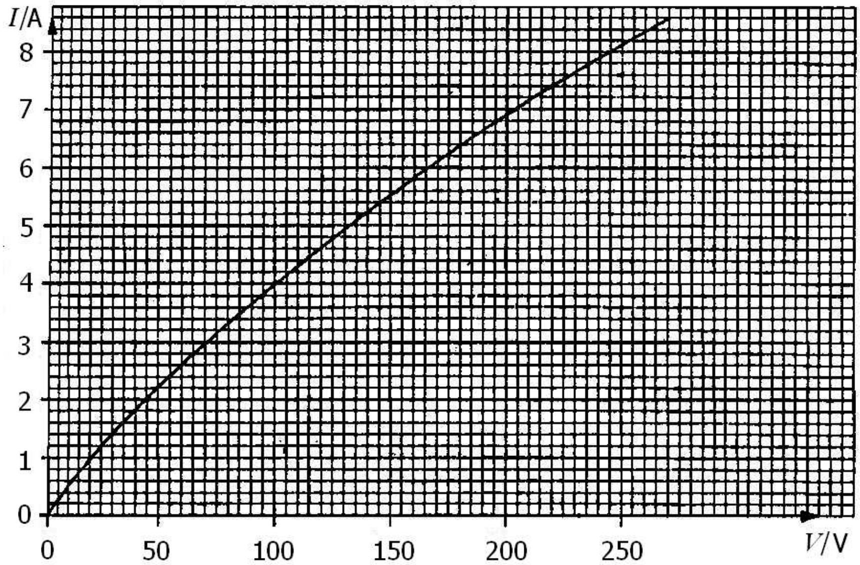
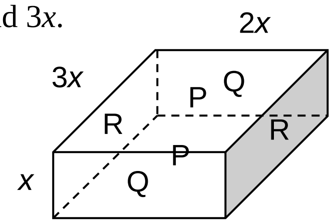


Figure 5

H1 students may stop after Q6 for HBL
H2 students must complete the whole set

6. The diagram shows a rectangular block with dimensions *x*, 2*x* and 3*x*. Electrical contacts to the block can be made between opposite pairs of faces of the block (i.e. between the faces marked R). Between which two faces would maximum electrical resistance be obtained?



7. A water heater is marked 230 V, 3000 W. It is switched on for 5000 s. For this heater, calculate

(a) the current through the heater [13 A]

(b) the resistance of the heater [17.7 Ω]

(c) the energy supplied by the heater during this time. [1.5×10^7 J]

8. A generator produces 100 kW of power at a potential difference of 10 kV. The power is transmitted through a cable of total resistance 5.0 Ω. What is the power loss in the cable? [500 W]

9. You are provided with two identical resistors and a d.c. power supply. What arrangement of resistors would give greatest power dissipated in the resistors when connected to the power supply? Explain why. [Parallel]

10. A battery of an e.m.f. of 12.0 V and an internal resistance of 0.05 Ω. Its terminals are connected to a load resistance of 3.00 Ω.

(a) Find the current in the circuit and the terminal potential difference of the battery. [3.93 A, 11.8 V]

(b) Calculate the power delivered to the load resistor, the power delivered to the internal resistance of the battery, and the power delivered by the battery. [46.3 W, 0.772 W, 47.1 W]

(c) As the battery ages, its internal resistance increases. Suppose the internal resistance rises to 2.00 Ω toward the end of its useful life. How does this affect the ability of the battery to deliver energy? Explain why. [Reduces energy]

11. When a battery of e.m.f. of 6.0 V is connected to a load of resistance R, the power dissipated in this load is 8.2 W. If the terminal potential difference of the battery is 5.7 V, determine

(a) the load resistance R, and [3.96 Ω]

(b) the internal resistance r of the battery. [0.21 Ω]