**Chapter 22: Electromotive Force and Potential difference**

***Please remember to photocopy 4 pages onto one sheet by going A3→A4 and using back to back on the photocopier.***

Remember (from Chapter 20**)**

**W = VQ**

**Electrical Power, Potential difference and Current**

We have seen in chapter 11 that

Power is defined as the rate at which work is done *or*

Power is the rate at which energy is converted from one form to another.

Most energy conversions in this section involve electrical energy converting to heat energy.

Remember 1 watt = 1 joule per second

Now if we take W = VQ and divide both sides by time (t), we get P = VI (because W/t = P, and Q/t = I)

**P = VI**

**Measuring Potential Difference**

* Voltages in Series: VTotal = V1 + V2
* Voltages in parallel are the same.\*
* A Voltmeter is used to measure Potential Difference.
* A Voltmeter is always connected in parallel with whatever it is measuring.

**Electromotive Force (emf)**

A voltage when applied to a full circuit is called an emf\*.

The unit of emf is also the Volt

**Some Sources of Electromotive Force (emf)**

* Mains
* Simple Cell
* Lead-acid accumulator
* Dry batteries
* Thermocouple

**Leaving Cert Physics Syllabus**

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| --- | --- | --- | --- |
| **Content** | **Depth of Treatment** | **Activities** | **STS** |
|  |  |  |  |
| **Sources of emf and electric current** | Pd and voltage are the same thing; they are measured in volts.  A voltage when applied to a circuit is called an emf. |  | Sources of emf: mains, simple cells, lead-acid accumulator, car  batteries, dry batteries, thermocouple. |

**Extra Credit**

We have noted already that one way of defining potential difference is by saying it is the work done when bringing a charge from one point to another.

This suggests that something has to do work *on the charge*.

But this is only if the charge in question is similar in sign to the sign of the charge it is going to, e.g. electron to negative terminal, or proton to positive terminal.

Alternatively we could define potential difference as the work done *by the charge* in going from one place to another, e.g. an electron moving towards a positive terminal.

But what does it mean to say that ‘the charge is doing work’?

Well, work is a form of energy, so the charge must be converting energy from one form to another (anytime work is being done, energy is being converted from one form to another).

In this case potential energy is being converted to kinetic energy (the charge speeds up), and when the charge reaches the terminal this kinetic energy gets converted in to a combination of heat and/or chemical energy.

Bottom Line, remember W = VQ?

This can be rearranged to give V = W/Q, which in physical terms means that the potential difference between two points can be defined as the work done as the charge goes from one point to the other divided by the charge itself.

Don’t be too surprised if you find this stuff confusing. Not only is it difficult to understand an abstract concept (it’s not like you can hold a bunch of voltage in your hand), but the meaning of the term ‘voltage’ has itself changed over the years, and you’re left to make sense of the remaining muddle!

If you think I’m just saying this to make you feel better, then read on.

*The following extract has been taken from the minutes of a History of Science meeting, in 2002.*

John Roche, of Linacre College, Oxford, opened the session after tea, speaking on the concept of voltage. He began by claiming that *almost every concept in electricity and electromagnetism is ambiguous, and the concept of voltage is one of the most incoherent*. Its evolution in difficult to follow.

Abbé Nollet, in the 18th century, distinguished quantity and degree of electrification. Others made similar distinctions between quantity and intensity or tension or pressure – what we would call voltage.

Roche showed how the term “voltage” had come to be used nowadays in three different ways; for electromotive force, potential difference and (absolute) potential.

Volta defined electrical tension as the endeavour of the electrical fluid to escape from a body. *Volta’s tension was more akin to a force, unlike the modern definition of electromotive force, which is a misnomer, being defined in terms of energy*.

Ohm carried Volta’s concept to closed circuits with the idea that voltage was proportional to the difference in tension between the ends of a conductor. For Ohm, it was the gradient of electrical tension that drove the current.

Poisson introduced an entirely different concept, of charge divided by distance to a point, which Green called the potential. This was an analytical device only, arising from an analogy with Laplace’s gravitational potential function.

Kirchhoff reconciled Volta’s tension with Poisson’s potential function through the concept of energy or *vis viva* introduced by Helmholtz. From Kirchhoff, current is driven by the electric field in a conductor and voltage is related to the energy supplied, but physicists and electrical engineers do not usually think of them in this way.

*All the earlier interpretations remain current*, but with different weights, and *most of the time* voltage is seen as a driving energy.

IOP History of Physics Group Newsletter, Spring 2000, page 65

**\*Voltages in parallel are the same**

This is a constant source of confusion for students and indeed I suspect for many teachers.

Allow me to try and clarify.

Consider two resistors in parallel: R1 is 100 Ohms and is in parallel with R2 - a 20 Ohm resistor.

The current in the 20 Ohm resistor will be five times greater than the current in the 100-Ohm resistor.

To calculate the voltage across each resistor, we simply multiply the resistance by the current (from V = R I), and find that the voltage across both is the same.

It should now be obvious why: If the resistance goes up by a factor of five, the current will go down by the same factor, therefore mathematically the product of resistance and current (i.e. the voltage) will be constant.

The confusion arises because you would think that the bigger resistor would require more work to push charge through.

This would indeed be the case if the same amount of current was passing through both resistors, but as we have just seen, this will not be the case if they are in parallel.

Clear as mud??

**\*A Voltage when applied to a full circuit is called an emf.**

I’m not sure this definition makes a whole lot of sense as it stands.

Let’s try to explain it.

You know that potential difference (voltage) is the work done in bringing charge from one point to another, e.g. across a resistor or some other apparatus.

Well if we wish to bring a charge around an entire circuit, i.e. from one terminal to the other, possibly passing through a number of resistors and other devices, then we express the *total* *work* *done* as ‘the emf’ of the circuit.

It could also be the case that the circuit is not complete, in which case the emf would represent the work which would be done in bringing charge from one point to another.

**Exam Questions**

1. [2003]

Explain the term *emf*

1. [2008 OL]

Name a source of potential difference.

1. [2002]

The ESB supplies electrical energy at a rate of 2 MW to an industrial park from a local power station, whose output voltage is 10 kV. Calculate the current.

1. [2004]

A table lamp has a power rating of 100 W. What is the most suitable fuse for the lamp (assuming mains voltage)?

1. [2003 OL]

The kettle has a power rating of 2 kW when connected to the ESB mains voltage of 230 V.

Calculate the current that flows when the kettle is first plugged in.

1. [2004 OL]

An electric heater has a power rating of 2 kW when connected to the ESB mains supply of 230 V.

Calculate the current that flows through the heater.

1. [2003 OL]

The fuse in the previous question is a 5 A fuse.

This current will only flow for a very short time. Explain why.

**Exam Solutions**

1. The term *emf* is used to describe a potential difference when it applies to a full circuit.
2. Battery, generator, thermocouple.
3. P = VI  = P/V  I =2 × 106/ 10 × 103 = 200 A
4. I = P/V  I = 100/230

Range: 0.5 A fuse

1. P = VI  I = P/V  I = 2000/230 = 8.7 A
2. P = VI ⇒ I = P/V ⇒ I = 2,000/230 = 8.7 A.
3. The current is larger than the fuse rating, so the fuse will blow.