Kilbaha Physics

VCE Unit 1

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CONTENTS - Kilbaha VCE Physics Unit 1

What ideas explain the physical world?

Authors' Note to Biology, Chemistry, Physics Teachers – Unit 1

- Ian Alexander, Alan Reynolds and Bill Healy as the authors and editors of this series have been motivated to complete this project by the new Study Guides for the VCE sciences for the period 2016 - 2021.

- Teachers will find that the content of these books goes well beyond the content of standard Year 11 Textbooks. We believe this will suit the new emphasis on research and investigation in the new Study Guides. We also expect these books to have wide application to other Australian Biology, Chemistry and Physics courses.

- We are keen to provide all schools with quality material at a bargain basement price.

- We have been able to do this because of the relationship between Kilbaha Multimedia Publishing in Australia and OpenStax in the United States. We are grateful to OpenStax for their support. It has taken considerable work to make these texts Australian in word and context and to meet the expectations of the new VCE courses commencing in 2016.

- Try to think of these electronic books in a different way. They are like Apps on your smartphone. These are just versions 1.1 and we envisage that additional material (free to all subscribers) will be added after feedback from teachers.

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- Schools can buy a one year unlimited school site licence for $25 per VCE Unit. We have Unit 1 available now for Biology, Chemistry and Physics. Unit 2 will be available shortly. Textbooks for Units 3 and 4 for Biology, Chemistry and Physics are also being planned for 2017. The Unit 3 and 4 Textbooks will be tightly focussed on the Year 12 Syllabi whereas the Year 11 Textbooks are wide-ranging in content.

- Ian Alexander, Alan Reynolds and Bill Healy hope that you find these electronic books a valuable addition to your teaching materials for Year 11 and Year 12 or wherever else you choose to use them within your school.

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- We will, of course, be delighted if you tell your colleagues about these books.

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Unit 1: What Ideas explain the physical world?
Area of Study 1: How can thermal effects be explained?

1.1 Thermodynamics: how does heat behave?

1.1.1 Temperature: how is it measured?

Figure 1.1.1
The welder's gloves and helmet protect him from the electric arc that transfers enough thermal energy to melt the rod, spray sparks, and burn the retina of an unprotected eye. The thermal energy can be felt on exposed skin a few metres away, and its light can be seen for kilometres. (credit: Kevin S. O'Brien/U.S. Navy)

Introduction to Temperature, Kinetic Theory, and the Gas Laws
Heat is something familiar to each of us. We feel the warmth of the summer Sun, the chill of a clear summer night, the heat of coffee after a winter stroll, and the cooling effect of our sweat. Heat transfer is maintained by temperature differences. The movement of heat energy from one place or material to another is apparent throughout the universe. Heat from beneath the Earth's surface is brought to the surface in glowing lava flows. The Sun warms the Earth's surface and is the source of most of its energy. Rising levels of atmospheric carbon dioxide threaten to trap more of the Sun's energy, perhaps fundamentally altering the ecosphere. In space, supernovas explode, briefly radiating more power than an entire galaxy does.

1.2. Thermodynamics and Climate Science

1.2.1 The Electromagnetic Spectrum

Electromagnetic waves are classified into categories such as radio, infrared, ultraviolet, and so on, so that we can understand some of their similarities as well as some of their differences.

Waves

An electromagnetic wave has a frequency and a wavelength associated with it and travels at the speed of light, *c*. The relationship among these wave characteristics can be described by $c = f\lambda$, where c is the speed of the wave, f is the frequency, and λ is the wavelength.

$$c = f\lambda \qquad (1.2.1)$$

Throughout this investigation *c*, is the speed of a light in a vacuum, 3.0×10^{8} ms^{-1}. The speed of light through the atmosphere is slightly less but this difference is unimportant in this study.

For all electromagnetic waves, the greater the frequency, the smaller the wavelength.

Figure 1.2.1 shows how the various types of electromagnetic waves are categorised according to their wavelengths and frequencies, it shows the electromagnetic spectrum. Many of the characteristics of the various types of electromagnetic waves are related to their frequencies and wavelengths.

1.3 Environmental Impacts of Human Activity

1.3.1 Proportion of National Energy Used in Heating and Cooling Homes

Research on the internet will give the answer, that households spend 40% of their supplied gas and electricity energy on heating and cooling.

The answer is the most recent value for Australia, based on 2008 data. This answer is very similar to that given for other countries with similar lifestyles. This answer is from credible sources, but your home could differ: this as a national average answer.

The question leads to others.

Think about the following options, which energy does this refer to?

- Is this the energy supplied by electricity, gas and other fuels to houses for heating compared to the total energy supplied to the household excluding that for work, outside entertainment and transport?
- Is this the energy used in maintaining the house as a liveable environment on a little planet at 150 million km from its star?
- Is this the energy used in the house itself, including that supplied to air-conditioners and heat pumps which transfer more energy than is supplied to them? Some houses use passive systems which would need to be accounted for in this summation.

The data is based on the first option. So how was this answer obtained?

- The energy used by households can be determined fairly easily, but which fraction is used in heating and cooling? Not all of these systems operate on off-peak electricity like hot water heaters.
- How will the answer change over a year as the seasons change?
- Would you install monitoring systems to find the energy used in a range of sample households?
- Would you ask householders how much energy they use?
- Would you ask the heating and cooling industry about the energy demands of the equipment they install?
- Knowing the environment in which people live, in what standard of housing, would you model the energy demands?

The core of the process is the last option, modelling, with some information from the others.

2.1 Concepts Used to Model Electricity

2.1.1 Fundamental Electrical Concepts

Charge and Current
There are many ways in which the role of charge can be observed.

Figure 2.1.1 Static electricity from this plastic slide causes the child's hair to stand on end. The sliding motion stripped electrons away from the child's body, leaving an excess of positive charges, which repel each other along each strand of hair. (credit: Ken Bosma/Wikimedia Commons)

In this case a child on a slide has created their own van de Graaff generator. The slide has stripped electrons from the child's clothing particularly. The child is missing a small fraction of the total electrons which they would normally have. The strands of hair are all slightly positively charged and try to repel each other. Such observations usually indicate the role of static electricity. Charges have been displaced and we see the result. Later we will see the charges return to normal and the hair will no longer stand up in this display.

The discovery of that electric charge had two forms, meant that names had to be given to the "electric fluids" as they were called. The one which we now associate with electrons was called "negative" and the other "positive". The opposite characteristics were indicated and the process was similar to the naming of the ends of a magnet as north and south. It

2.2 Electricity in Circuits

2.2.1 Resistors and their Graphs

The Difficulty in Moving a Charge Through a Circuit

In the initial modelling of the circuit, there was a suggestion that dropping a charge in would require work to be done. This work could also vary from one situation to another. We might also anticipate that the difficulty of forcing a charge through a circuit would restrict the current and that this restricted current flow would be proportional to the voltage driving the current.

Georg Ohm

The electric property that impedes current is called resistance (R). Collisions of moving charges with atoms and molecules in a substance transfer energy to the substance and limit current. The wire is heated in these collisions. Resistance is defined as the ratio of potential difference (voltage) driving the current, compared to the current, or

$$R = V / I \qquad (2.1.4)$$

The German physicist George Ohm observed that over a wide range of conditions, the value of resistance was fixed and determined the voltage - current ratio in the materials he had investigated. This relationship is called Ohm's law and in this form defines resistance for certain materials and restricted conditions. Ohm's law is not universally valid, but describes metallic and carbon conductors within a limited temperature tolerance. An object which has this simple resistance is called a resistor, even if its resistance is small. The unit for resistance then is then a volt-amp^{-1} called an ohm and is given the symbol Ω. (Capital omega in Greek). It can be assumed valid for the resistors used in electronic circuitry.

If Ohm's Law is generally valid and not just a measurement to make under some conditions (like the globe in **Section 2.1**), then a graph can be drawn of the resistor's characteristics. Using $I = V / R$ the graph will have a gradient $= 1 / R$.

In **Figure 2.2.1**, the graph is a straight line, because the gradient is constant, at least up to 10 V. This device is called "ohmic" because the resistance is also constant. If the gradient had changed, bending the line up or down, the device would be called "non-ohmic". There are some important non-ohmic devices.

2.3 Using Electricity

Figure 2.3.1 This power adapter uses metal wires and connectors to conduct electricity from the wall socket to a laptop computer. The conducting wires allow charge to move freely through the cables, which are insulated with plastic. (credit: Evan-Amos, Wikimedia Commons)

2.3.1 Electronic Circuits and Transducers

Electricity has given us several separate processes which

- transfer energy.
- give control over the way equipment operates
- enable the storage of data
- do work as motors

Electric and electronic processes have proven more successful than all of the alternatives.

In this section we begin to look at the way electricity allows us to control other devices. This commonly involves devices classed as transducers. These are devices which have an electric aspect and also an interaction with the outside environment.

Output transducers can start with an electrical input and an external output. Or this can be reversed, for an input transducer, so that an environmental change produces an electric change. In the first case this could be as simple as a light. Electric power passes through the device and light is produced using this power. In the second case it could be a light detector, which produces an electric signal when the light intensity on a sensor changes.

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Unit 1: What Ideas explain the physical world?
Area of Study 2: How do electric circuits work?

2.4 Electricity and Safety

2.4.1 Household Wiring and Components

The Circuit in a House
We have seen the basic parallel wiring of household electricity to supply lights and power points. The actual wiring develops this further and includes important safety features. A check on a household power board will show a row of switches or perhaps fuses. The power supply to the house is separated into sections, a number of circuits will supply power points and commonly two more would supply lighting. There will be further circuits for ovens and air-conditioners. They may also be a section controlling photo-voltaic cells and its inverter.

The separate circuits divide the current demand, and this reduces the size of the copper wiring which needs to be installed. Each circuit carries a lower total current. When a high current flows under fault conditions, perhaps 100 A, it is easier to detect, compared to the usual currents which are lower, less than 20 A

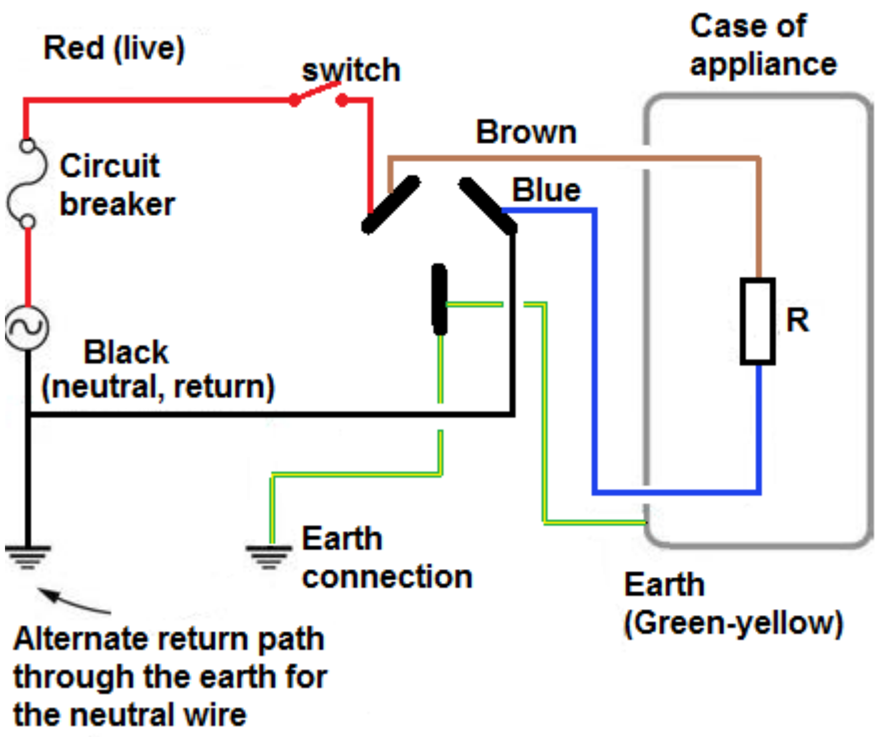

Figure 2.4.1 Shows a basic three wire system used in household wiring.
The wiring is shown at a power point, **socket view**.

Author's diagram

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Area of Study 3: What is matter and how is it formed?

3.1 The Big Bang and Particle Physics

3.1.1 Scientific Notation and the Big Bang

The Système International
Previously in **Section 1.1.6**, the metric system has been briefly introduced, including a range of prefixes which are used to help manage the size of the numbers involved as we deal with all the measurements which can be made of the universe. See **Table 1.1.3**

The metric system has a number of fundamental units. These are:

distance:	metre	m
mass:	kilogram	kg
time:	second	s
electric current:	Ampere (amp)	A

The metric system is sometimes known for these units as the mks or mksA system.

The remaining fundamental units are:

temperature	kelvin	K
amount	mole	mol
luminous intensity	candela	cd

All other units are derived from these seven units. The joule, watt, volt, etc. can all be expressed in terms of the fundamental seven.

This text has also used scientific notation. This is an alternative way of managing the numbers which need prefixes. Scientific notation, allows for calculations to be carried out without converting units; the units will always work together.

3.2 Nuclear Structure

3.2.1 Nuclear Stability and its Short Distance Forces

We have seen that in the Big Bang, the unified super-force separated into four fundamental forces. **Table 3.2.1**. is a summary of the properties of these four separated forces.

Table 3.2.1 The Four Forces

Force	Comparative strength	Positive and negative forces	Range
gravity	10^{-38}	positive for all matter	infinite
electromagnetic	10^{-2}	attractive and repulsive	infinite
weak	10^{-13}	attractive and repulsive	$< 10^{-18}$ m
strong	1	attractive and repulsive	$< 10^{-15}$ m

Considering the particles in a nucleus, the positively charged protons will repel each other and there is no attraction to the neutrons. Gravity is too weak to provide an attractive force against such strong repulsion. It is the strong force which is attractive at nuclear distances, irrespective of the particle's charge. It is repulsive to adjacent particles. It can provide a balance to the repulsion provided by electromagnetic forces.

The atom needs an increasing number of neutrons in the nucleus to balance the electromagnetic repulsive forces which operate at a long distance. As a result we see that the ratio of neutrons to protons increases as the elements become heavier. In helium $^{4}_{2}He$ the "2" counts the protons and the "4" counts the sum of protons and neutrons. The number of neutrons must be 2. For iron $^{56}_{26}Fe$ the ratio is 1.154 and for the heaviest stable isotope lead $^{208}_{82}Pb$ it is 1.537. There are heavier elements found in nature and some have immensely long lives, but this is the heaviest stable isotope.

There are three broad conditions then for radioactivity. Elements heavier than lead are radioactive: similarly even if lighter than lead, elements with low or high neutron/proton ratios are also radioactive.

Elements with 2, 8, 20, 28, 50 or 82 protons tend to be stable. Odd numbers of neutrons and protons tends to indicate instability.

The weak force is also a nuclear force but it does not help hold the nucleus together. It acts differently on protons and neutrons and can make radioactive decays possible as well as fission and fusion processes. It does not act on the protons and neutrons but can act on the quarks inside them.

Energy from the atom

3.3.1 Energy and Mass

Mass Defect
In **Section 3.2.7** we saw in the α decay of uranium to thorium that the mass of uranium was greater than the mass of thorium and α particle. The difference in mass, the mass defect was converted to energy by Einstein's mass- energy equivalence $E = mc^2$.
In that case the mass defect (loss) compared to the initial mass was 0.0046 / 238.0003 = 0.0019%

Binding Energy
The more tightly bound a system is, the greater the energy required to pull it apart. So we can learn about nuclear forces by examining how tightly bound the nuclei are. We define the binding energy E_B of a nucleus to be the energy required to completely disassemble it into separate protons and neutrons. We can determine the E_B of a nucleus from its rest mass. The two are connected through Einstein's famous relationship $E_B = \Delta mc^2$. The symbol Δm is used here because there is a change in mass when the particles bind into a nucleus. A bound system has a smaller mass than its separate constituents; the more tightly the nucleons are bound together, the smaller the mass of the nucleus. The greater the mass defect.

Imagine putting a nuclide together as illustrated in **Figure 3.3.1**. Energy is released as the particles "fall" together, like an apple falling to the ground. In this case the attraction is the nuclear strong force and if the particles were to be separated this energy would have to be replaced. This then is the binding energy E_B, the energy needed to separate the particles. When the particles are put together energy is released, and mass is measurably reduced. That mass decrease or defect is given by $\Delta m = E_B / c^2$.
This difference in mass is known as mass defect. It implies that the mass of the nucleus is less than the sum of the masses of its constituent protons and neutrons.

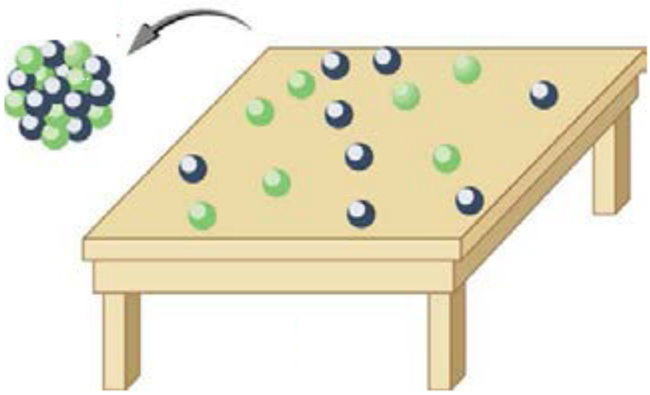

Figure 3.3.1 Energy released in putting a nucleus together from its constituent protons and neutrons decreases the mass of the system. The energy released in constructing the nucleus equals its binding energy E_B . A bound system has less mass than the sum of its parts, which is especially noticeable in nuclei, where forces and energies are very large.

Figure modified from OpenStax Physics

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