3

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

National Certificate of Educational Achievement
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Level 3 Physics, 2006

90522 Demonstrate understanding of atoms, photons and nuclei

Credits: Three
9.30 am Monday 20 November 2006

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should answer ALL the questions in this booklet.

For all numerical answers, full working must be shown, and the answer must be rounded to the correct number of significant figures and given with an SI unit.

For all 'describe' or 'explain' questions, the answers should be written or drawn clearly with all logic fully explained.

Formulae you may find useful are given on page 2.

If you need more space for any answer, use the page(s) provided at the back of this booklet and clearly number the question.

Check that this booklet has pages 2–8 in the correct order and that none of these pages is blank.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

For Assessor's use only	Achievement Criteria	
Achievement	**Achievement with Merit**	**Achievement with Excellence**
Identify or describe aspects of phenomena, concepts or principles. ✓	Give explanations in terms of phenomena, concepts, principles and/or relationships. ✓	Give explanations that show clear understanding in terms of phenomena, concepts, principles and/or relationships. ✓
Solve straightforward problems. ✓	Solve problems. ✓	Solve complex problems. ✓
Overall Level of Performance (all criteria within a column are met)		E

You are advised to spend 35 minutes answering the questions in this booklet.

Assessor's use only

You may find the following formulae useful.

$E = hf$	$hf = \phi + E_K$	$E = \Delta mc^2$	$E_n = -\frac{hcR}{n^2}$
$\frac{1}{\lambda} = R(\frac{1}{S^2} - \frac{1}{L^2})$	$E_p = qV$	$v = f\lambda$	

QUESTION ONE: NUCLEAR REACTIONS

Mass of nuclei:

- neutron: 1.67492×10^{-27} kg
- proton: 1.67353×10^{-27} kg
- deuterium: 3.34449×10^{-27} kg
- tritium: 5.00827×10^{-27} kg
- helium-4: 6.64648×10^{-27} kg
- lithium-6: 9.98835×10^{-27} kg

Speed of light = 3.00×10^8 m s^{-1}

Three bottles of water and some rocks can provide, in theory, enough energy for a family for one year. The water and rocks can be used to obtain the raw materials for a thermonuclear reaction that can take place between deuterium and tritium.

Tritium can be made from lithium $^6_3$Li, which can be extracted from the rocks.

(a) Show that the mass deficit of a lithium nucleus is 5.700×10^{-29} kg.

$M_{d,Li}$ = (mass of 3 proton + 3 neutron) − (mass of lithium)

$= ((1.67492 \times 10^{-27} \times 3) + (1.67353 \times 10^{-27} \times 3)) - 9.98835 \times 10^{-27}$

$= 5.700 \times 10^{-29}$ kg

A2

(b) Calculate the binding energy per nucleon for the lithium nucleus.

Binding energy = mass deficit × c^2 or $E = mc^2$

$= -5.700 \times 10^{-29} \times (3.00 \times 10^8)^2 = 5.13 \times 10^{-12}$ J

6 nucleons ∴ binding energy per nucleon $= \frac{-5.13 \times 10^{-12}}{6} = 8.55 \times 10^{-13}$ J

M2

binding energy per nucleon = 8.55×10^{-13} J

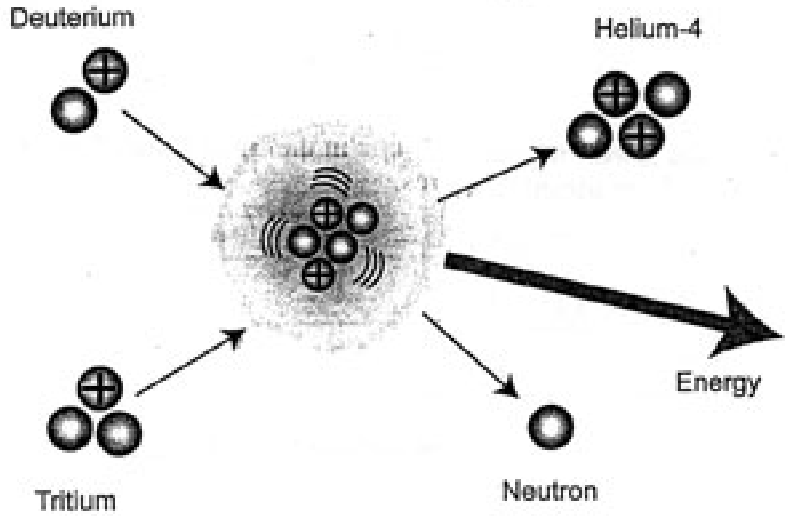
Assessor's use only

(c) State how the binding energy per nucleon can indicate the **stability** of a nucleus.

The binding energy per nucleon is the energy required per nucleon to break up a nucleus into individual nucleons. The higher the binding energy per nucleon, the harder it is to break up a nucleus, so the more stable the nucleus.

A1

Deuterium (hydrogen−2) can be extracted from the water. Thermonuclear reactors heat a mixture of deuterium and tritium to 100 million degrees Celsius to produce the reaction illustrated below.



Source www.iter.org

The nuclear equation for this reaction is: ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$

(d) Calculate the amount of energy produced in this reaction.

mass deficit = $(3.34449 \times 10^{-27} + 5.00827 \times 10^{-27}) - (6.64648 \times 10^{-27} + 1.67492 \times 10^{-27})$

mass deficit = 3.1360×10^{-29} kg

Energy = mass deficit × c^2 = 2.8224×10^{-12} J = 2.82×10^{-12} J (3 s.f.)

energy = 2.82×10^{-12} J

M2

(e) Explain why it is necessary for the temperature to be **so high** for this reaction to occur.

For this reaction to take place, the reactants have to be broken apart, so the products can form. To break the reactants apart energy equivalent to their binding energy must be provided. Therefore, for this reaction to take place in a large number of Deuterium and Tritium nucleus, a lot of energy is required. This is added by increasing the temperature, meaning there needs to be a very large temperature for this reaction to take place.

high temp – high energy
but no sense of collision

NA

QUESTION TWO: SOLAR POWER

Assessor's use only

Rydberg's constant $= 1.097 \times 10^7 \text{ m}^{-1}$
Planck's constant $= 6.63 \times 10^{-34}$ J s
Speed of light $= 3.00 \times 10^8 \text{ m s}^{-1}$

Nuclear reactions in the Sun produce light. The main element in the Sun is hydrogen. The spectrum of hydrogen can be observed in the laboratory with a hydrogen discharge tube.
The visible lines in the hydrogen spectrum are called the Balmer series and are described by the formula:

$$\frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$$

where $S = 2$.

(a) Calculate the wavelength of the lowest frequency line in the Balmer series (L = 3). Give the answer to the correct number of significant figures.

$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{L^2}\right) = 1.097 \times 10^7 \left(\frac{1}{2^2} - \frac{1}{3^2}\right)$

$= 1523611.1\ldots$

$\lambda = \frac{1}{1523611.1\ldots} = 6.56335\ldots \times 10^{-7}$ m

wavelength = 6.563×10^{-7} m (4sf)

(5f) + 4(4)

A2

A1

(b) Explain how light of **this particular** frequency is produced in the hydrogen atom.

when an electron in the hydrogen is excited to a higher energy level due to the addition of energy, it can then fall back to a lower energy level. to do this, it must release energy as a photon of light. The energy of this photon is the same as the difference in energy between the two energy levels. As $E = hf$, this energy determine the f of the photon. To produce this particular frequency, a electron in the hydrogen atom has to be excited to the 3rd energy level, and then fall back to the second energy level, by emitting a photon at this frequency.

M1

(c) An electron in the 6th excited state (L = 7) returns to the ground state in two jumps. It releases one photon with a wavelength of 2.165×10^{-6} m.

Assessor's use only

What is the wavelength of the second photon?

~~$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{7^2}\right)$~~

~~$\frac{1}{\lambda} = 1.097\times10^{7}\left(\frac{1}{1^2} - \frac{1}{7^2}\right)$~~

~~$\lambda = 3.770\times10^{-7}$ m~~

$\frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$

$\frac{1}{2.165\times10^{-6}} = 1.097\times10^{7}\left(\frac{1}{S^2} - \frac{1}{7^2}\right)$

$S = 3.999... = 4$

$\frac{1}{\lambda} = 1.097\times10^{7}\left(\frac{1}{1^2} - \frac{1}{4^2}\right)$

$\lambda = 9.723\times10^{-8}$ m

E2

wavelength = 9.723×10^{-8} m

(d) The Sun emits **all** wavelengths. However, when a solar spectrum is observed on Earth, it contains black lines that correspond to missing wavelengths.

Give an explanation, in terms of energy absorption by electrons, for why some of the wavelengths of light in the solar spectrum are missing when the light reaches Earth.

when the light from the sun hits earth's atmosphere, some wavelengths of it are absorbed by electrons in substances in the atmosphere. This energy absorbtion causes electrons to jump to higher energys, and when the fall down again, they do it in steps, releasing different wavelength photons to the incident photons. this means that some wavelengths do not reach the surface of the earth, resulting in black lines in the solar spectrum.//

E1

all the required points + reasonable explanation of why they are not re-emitted!

Assessor's use only

QUESTION THREE: NIGHT VISION CAMERA

Planck's constant = 6.63×10^{-34} J s

A night vision camera, like the one shown below, detects low levels of light on the photo-cathode, which releases a few electrons. A photomultiplier increases the number of electrons, which then hit the screen to produce an image.

(a) Name the **effect** that causes electrons to be released by the photo-cathode.

The Photo-Electric effect. A1

(b) The photo-cathode material of this night vision camera prevents it detecting infrared radiation. State **why** this is so.

For electrons to be emitted, the incident photons must have ~~enough~~ the same or higher energy than the work function of the cathode material. $E = hf$, and infrared radiation has a to lower frequency, and therefore Energy, to overcome the work function. A1

The photo-cathode is made of a material that has a work function of 2.58×10^{-19} J.

(c) Calculate the lowest frequency of light that could release a photoelectron.

$E_{min} = \phi = h f_{min}$

$f = \frac{2.58 \times 10^{-19}}{6.63 \times 10^{-34}} = 3.8914 \times 10^{14}$ Hz

$= 3.90 \times 10^{14}$ Hz (rounding up as it is a min)

frequency = 3.90×10^{14} Hz A2

ignore incorrect rounding.

Assessor's use only

(d) Explain the effect on the number **and** energy of the electrons released when the frequency of the light is decreased.

As the frequency of the incident photons decreases, so does the energy ~~stored~~ given to the electrons that absorb them. because of this decrease, there is also a decrease in energy of released electrons after overcoming the work function.

As electrons ~~the~~ in a substance have varying base energys, reducing the energy provided by the photons also reduces the number of electrons that can overcome the work function, so less electrons are released. //

final statement does not match schedule, or what is taught, but is actually correct physics and displays a higher level of understanding than level 3.

E1

The photo-cathode is replaced with a different material. When it is illuminated with light of wavelength 2.80×10^{-7} m, electrons with a maximum kinetic energy of 3.04×10^{-19} J are produced.

(e) Calculate the threshold frequency for the material.

$hf = \phi + E_k$

$6.63\times10^{-34} \times \frac{3.00\times10^{8}}{2.80\times10^{7}} - 3.04\times10^{-19} = \phi$

$\phi = 4.06\times10^{-19}$ J

$\phi = E = hf$

$f = \frac{\phi}{h} = \frac{4.06\times10^{-19}}{6.63\times10^{-34}} = 6.13\times10^{14}$ Hz

threshold frequency = 6.13×10^{14} Hz

E2.