YEAR 12 PHYSICS, UNIT 4

2016 Wave-Particle Duality and Quanta Test

NAME: Solutions

TOTAL MARKS: /50

TIME ALLOWED FOR THIS PAPER

Working time for paper: Sixty minutes

MATERIAL REQUIRED/RECOMMENDED FOR THIS PAPER

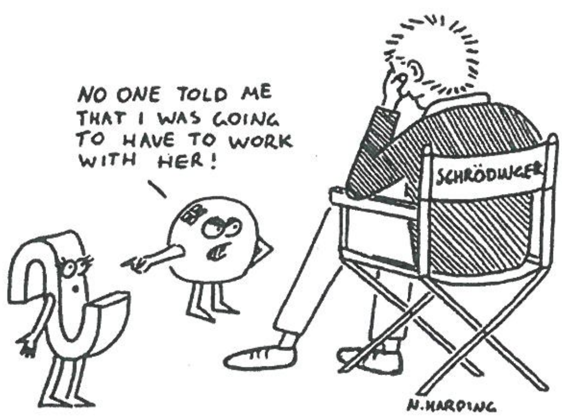
TO BE PROVIDED BY THE SUPERVISOR

This Question/Answer Booklet.
Physical formulae and constants sheet.

TO BE PROVIDED BY THE CANDIDATE

Standard Items: Pens, pencils, eraser, correction fluid, ruler, highlighters.

Special Items: Non-programmable calculators satisfying the conditions set by the Curriculum Council for this course, drawing templates, drawing compass and a protractor.



SECTION A: Short Answers

Marks allocated: 26 out of 50 total (52%)

This section contains 6 questions. Answer ALL of the questions and show full working.

Question 1 [4 Marks]

Electromagnetic waves are said to be both wave-like and particle-like. Give an example where electromagnetic radiation behaves as if it was a wave and an example of where it behaves like a particle. Explain the wave or particle properties of each example.

WAVE BEHAVIOUR – YOUNG'S DOUBLE SLIT EXPERIMENT ✓

(or) - diffraction is a wave phenomenon ✓
- interference " " " " "

PARTICLE BEHAVIOUR – PHOTOELECTRIC EFFECT ✓

(or) - increased I below work function does not eject electrons
- existence of a threshold frequency suggests quantised energy.

Question 2 [5 marks]

a) Many people complain that fluorescent lights produce a different kind of light to traditional incandescent lights. With reference to the basic mechanism behind the productions of light and the type of spectra produced, explain how and why the light produced by these two sources is different (4)

Incandescent is produced by a hot metal filament which produces a continuous spectrum ✓

Fluorescent light is produced by* passing an electric current through a gas ✓ and is a line emission spectrum ✓

b) Why are incandescent globes relatively inefficient? (1)

- Much of the energy produced is outside the visible spectrum

(or) More heat is produced than light.

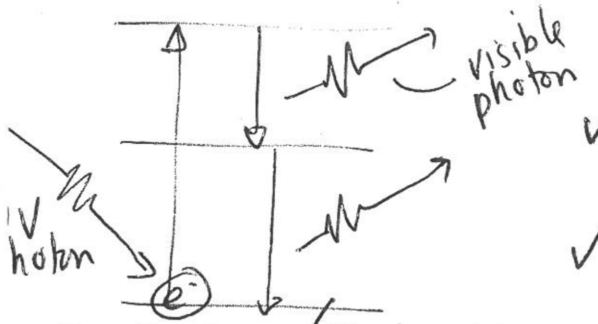
* Any reference to excited electron states, etc is OK. Technically it is the inner coating of the tube that fluoresces visible light, not the initially produced EMR in the tube

Question 3 [3 Marks]

Some substances appear to glow under ultraviolet light.

a) What is the name of this phenomenon? Fluorescence (1)

b) Explain how this phenomenon occurs. Include a diagram in your explanation. (2)



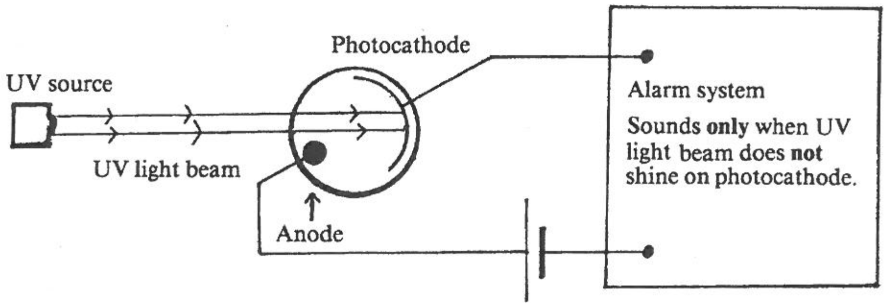
* Electrons absorb high energy UV ✓ photon & move to high energy level.

✓ * Returns to ground state in 2 or more jumps producing lower energy photons

(* These ideas may be conveyed by diagram (-1 if no diagram))

Question 4 [4 marks]

The diagram below shows part of the circuit for a burglar alarm.



The alarm system is arranged in such a way that, when ultra-violet (UV) light shines on the photocathode, the alarm does **not** sound but when the UV light beam is broken the alarm will start to sound.

a) Which of the statements (A-D) below is the best explanation of the effect of shining UV light on the photocathode? ✓✓

A The UV light photons eject electrons from the photocathode causing an electric current to flow in the circuit.

B The UV light photons eject positive charges from the photocathode causing an electric current to flow in the circuit.

C The UV light prevents electrons from being ejected from the photocathode, hence the alarm sounds only when the beam is broken.

D The UV light deflects electrons which normally flow from the photocathode to the anode.

The ultra-violet light source is now replaced by a source of red light.

b) Which of the statements (A-D) below best describes the result of this replacement?

A The alarm will definitely operate as normal.

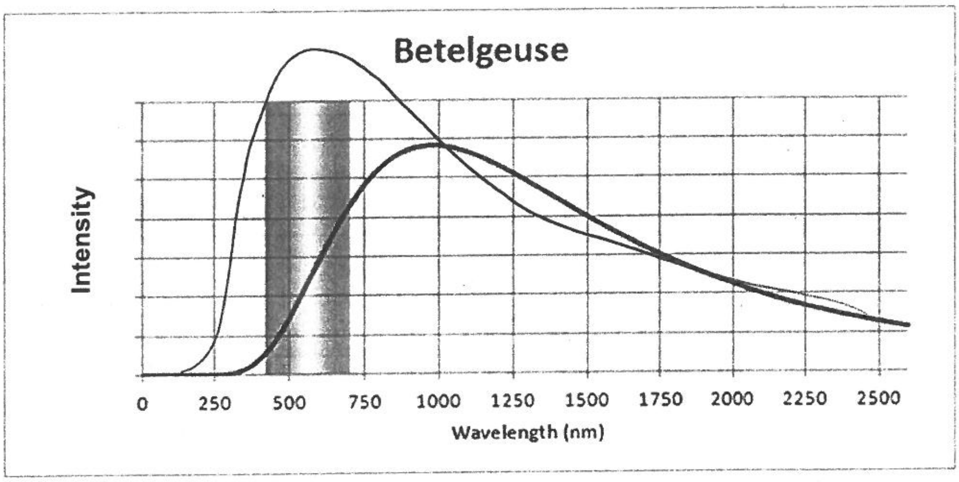
B The alarm will now ring whether or not the light beam is broken.

C The alarm will now ring when the light beam is shining but will stop when the beam is broken.

✓ D Whether or not the alarm will operate normally depends on the value of the work function of the photocathode material.

Question 5 [4 Marks]

The electromagnetic spectrum of the star Betelgeuse is shown below. Like most stars, the spectrum is very close to that of an ideal black body radiator. The range of wavelength of visible light is shown by the vertical column (not shown in colour).



a) What colour would you expect Betelgeuse to appear? red/orange ✓ (1)

b) Wein's law relates surface temperature (in Kelvin) to the peak wavelength of an ideal black body emission spectrum:

$$\lambda_{max} = \frac{b}{T}$$

where is a constant $= 2.898 \times 10^{-3}$ m K

Use this law to evaluate the surface temperature of Betelgeuse (1)

$$T = \frac{b}{\lambda} = \frac{2.898 \times 10^{-3}}{950 \times 10^{-9}} = 3050\ K$$ ✓

c) Betelgeuse' neighbouring star Bellatrix has a much hotter surface temperature of over 20000 K. Draw a curve on the graph above to show a possible spectrum of Bellatrix (you do not need to calculate the peak wavelength) (2)

peak is to the left ✓

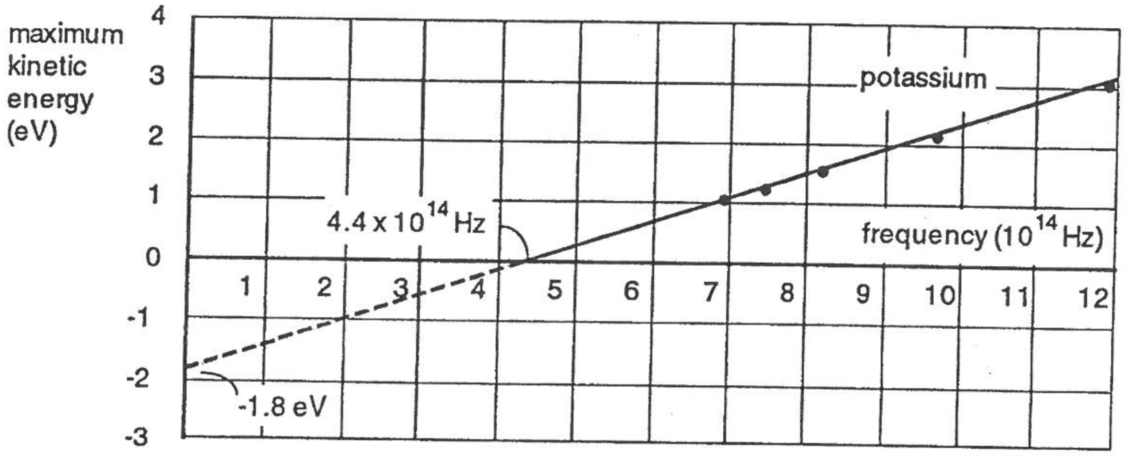
peak is higher ✓

Question 6

[5 marks]

In early experiments to investigate the photoelectric effect, a beam of light of a single frequency was directed at a clean surface of potassium metal. The maximum kinetic energy of electrons which were ejected from the metal was measured.

When the experiment was repeated with different frequencies of light the maximum kinetic energy of electrons depended on the frequency of the light as shown below.



a) What is the minimum energy of a light photon that can eject an electron from potassium metal? (Answer in units of eV) (1)

1.8 eV ✓

b) Light of a frequency 9×10^{14} Hz is shone on the potassium. Calculate the maximum kinetic energy of the resultant ejected electrons.

$W = 1.8 \times 1.6 \times 10^{-19} = 2.88 \times 10^{-19}$ (Note: if you use 4.4×10^{14} Hz, $W = \underline{2.917 \times 10^{-19}\,J}$)

$E_K = hf - W$

$= 6.63 \times 10^{-34} \times 9 \times 10^{14} - 2.88 \times 10^{-19}$ ✓

$= 3.09 \times 10^{-19}\,J$ ✓ (or $3.05 \times 10^{-19}\,J$)

c) Calculate the minimum stopping voltage for this frequency (2)

$Vq = E_K$

$\Rightarrow V = \dfrac{3.09 \times 10^{-19}}{1.6 \times 10^{-19}}$ ✓

$= 1.93\,V$ (or $1.91\,V$) ✓

SECTION B: Problem Solving Marks Allotted: 25 marks out of 50 (50%)

This section contains 4 questions. Answer ALL of the questions in the space provided and show full working.

Question 7 [7 Marks]

A special laser used in eye surgery emits a 200 mW pulse at a wavelength of 1060 nm, focused to a spot on the retina. The pulse lasts for 0.02 seconds.

a) Calculate the frequency of this laser light. (2)

$$f = c/\lambda = \frac{3\times10^8}{1060\times10^{-9}} = 2{\cdot}83\times10^{14}\ \text{Hz}$$

✓ ✓

b) In what region of the electromagnetic spectrum does this laser operate? (1)

Infra red ✓

c) Calculate the energy of one photon of this laser light. (2)

$$E = hf = 6{\cdot}63\times10^{-34}\times 2{\cdot}83\times10^{14}$$ ✓

$$= 1{\cdot}88\times10^{-19}\ \text{J}$$ ✓

d) Calculate the number of photons of light produced in a pulse (2)

$$E = P\times t$$

$$= 200\times10^{-3}\times0{\cdot}02$$

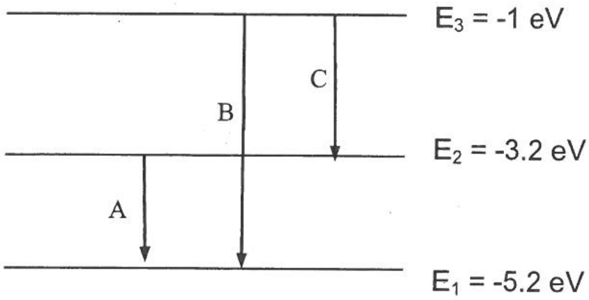
$$= 4\times10^{-3}\ \text{J}$$

$$\text{no. of photons} = \frac{E}{E_{ph}} = \frac{4\times10^{-3}}{1{\cdot}88\times10^{-19}}$$

$$= 2.13\times10^{16}$$

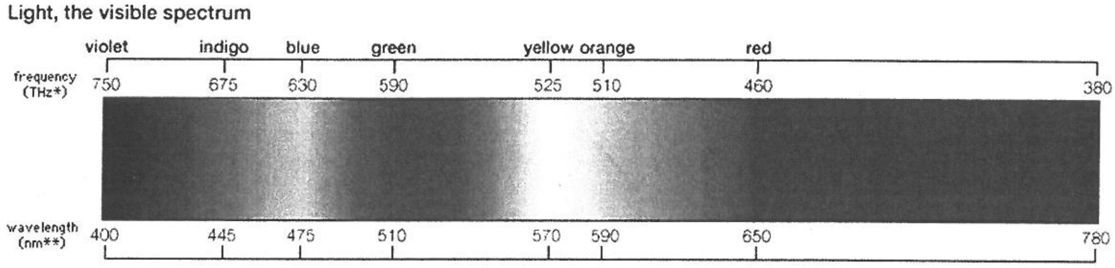
Question 8 [4 Marks]

An aurora is the appearance of coloured "curtains" of light in the sky near the Earth's poles. The light comes from the atoms high in the atmosphere which have been "excited" by streams of charged particles entering the atmosphere from the sun or from the Earth's radiation belts. The green colour in an aurora is due to the emission from excited oxygen atoms.



Part of the energy level diagram for oxygen is given on the right:

Which electron transition (A, B or C) is responsible for the green light? (Show all calculations and reasoning). The visible spectrum is shown below.



$f_{green} \approx 590 \times 10^{12}$ Hz ✓

$E_{ph} = 590 \times 10^{12} \times 6.63 \times 10^{-34}$

$= 3.9117 \times 10^{-19}$ J

$= 2.44$ eV. ✓

A → $\Delta E = 5.2 - 3.2 = 2$ eV

B → $\Delta E = 5.2 - 1 = 4.2$ eV ✓

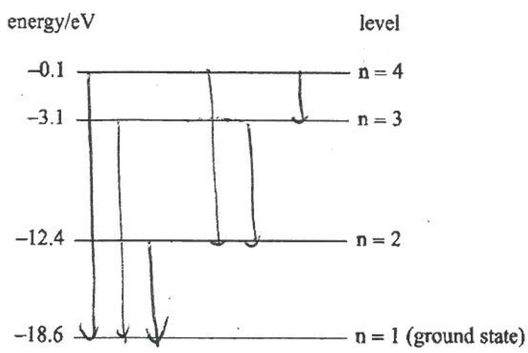
C → $\Delta E = 3.2 - 1 = 2.2$ eV.

Transition C is responsible ✓

(Check: $2.2 \Rightarrow 2.2 \times 1.6 \times 10^{-19}$
$= 3.52 \times 10^{-19}$ J
$f = E/h$
$= 531 \times 10^{12}$ Hz
≡ light green)

Question 9 [6 Marks]

The diagram shows some energy levels, in eV, of an atom.



a) How many emission lines are possible from electron transitions **to the ground state** of this atom? (1)

3

b) How many emission lines are possible in total? (1)

6

c) What is the ionisation energy, in eV, for an electron in the ground state? (1)

18.6 eV ✓

d) In its ground state the atom is bombarded by an electron having 2.1 x 10^{-18} J of energy. Calculate the possible energies in eV, with which this electron could be scattered from the atom after the collision. (3)

$$E_{e^-} = 2.1 \times 10^{-18} \text{ J} = \frac{2.1 \times 10^{-18}}{1.6 \times 10^{-19}} = \underline{13.125 \text{ eV}}$$ ✓

Possible energies:

6.4

$= 13.125 - (18.6 - 12.4)$

$= \underline{6.93 \text{ eV}}$ ✓

or $\underline{13.1 \text{ eV}}$ ✓

Question 10 [8 Marks]

De Broglie's postulate was that moving particles can be considered as waves with an associated wavelength.

a) Calculate the de Broglie wavelength for a 200-gram cricket ball bowled towards a batsman at 40 m/s. (1)

$\lambda = \frac{h}{mv} = \frac{6.63\times10^{-34}}{0.2\times40} = 8.29\times10^{-35}\ m$ ✓

b) The batsman missed the ball. Use your result from (a) to explain why the path of the cricket ball will not diffract around the edge of his bat. (2)

Bats are around 10 cm wide.
Diffraction occurs when wavelength is comparable in size to objects/gaps. ✓
8.29×10^{-35} m is much too small ✓

c) Calculate the de Broglie wavelength for an electron after it is accelerated through a 200 volt potential (3)

$\frac{1}{2}mv^2 = Vq$ ✓

$v = \sqrt{\frac{2Vq}{m}}$

$= \sqrt{\frac{2\times200\times1.6\times10^{-19}}{9.11\times10^{-31}}}$

$= 8.38\times10^{6}\ ms^{-1}$ ✓

$\lambda = \frac{h}{mv} = \frac{6.63\times10^{-34}}{9.11\times10^{-31}\times8.38\times10^{6}}$

$= 8.68\times10^{-11}\ m$ ✓

d) Circle any and all accurate statements about de Broglie's postulate listed below (2)

½ 1. It suggested a reason for Bohr's quantisation of electron energy levels in atoms.
½ 2. It suggested that electrons in atoms can be considered as standing waves
½ 3. It explained why electrons have momentum
½ 4. The location of particles in motion can be considered to be 'spread out' over a distance rather than located at a particular point.

END OF TOPIC TEST