PARTICLES

A LEVEL PHYSICS

EXAMINATION PREPARATION BOOK

STUDENT BOOK

TOPIC BOOK

NAME	
PHYSICS CLASS	
MODULE TEACHER	
ALPS GRADE	

Please complete all of these questions in this book and store this work in your student files.

This will provide a useful resource for revision.

In the following booklet there are several questions based on the module '3.2 Particles and Radiation'. These questions are additional to the work which you must do on your A-Level course.

To gain the highest grade possible in your A-Level examinations it is recommended that you complete these questions in the supervised study sessions carried out in school.

This will both familiarise yourself with both the concepts found in the A-Level syllabus and the examination technique found in examinations.

The mark scheme to the questions is integrated in the book for you to use independently.

To improve competency in answering questions on mechanics and materials and achieve mastery in this module, answer all of these questions independently.

When you have completed your work in this book, please store this work in your student files.

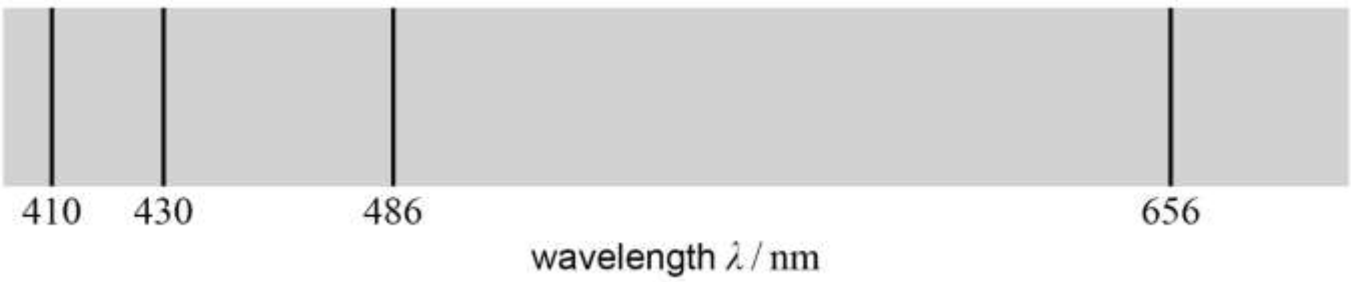
Many thanks for all of your hard work in A-Level Physics.

Mr. Turnbull

QUESTION ONE

1. In a discharge tube a high potential difference is applied across hydrogen gas contained in the tube. This causes the hydrogen gas to emit light that can be used to produce the visible line spectrum shown in **Figure 8.**

Figure 8

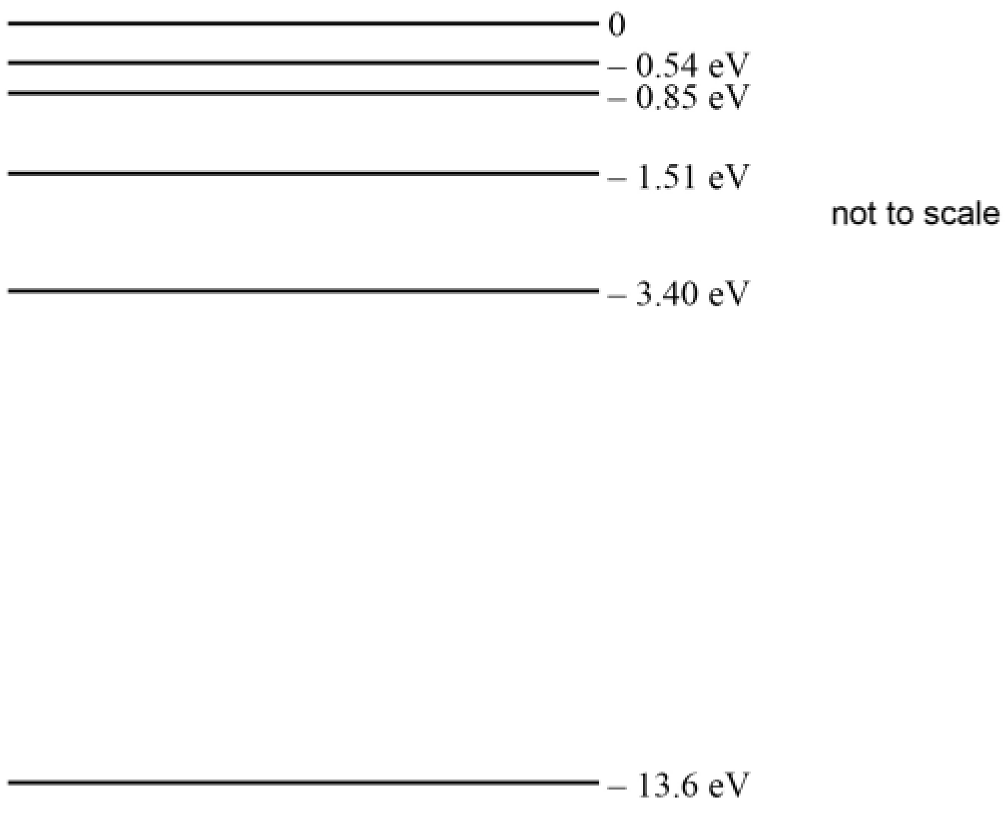


The visible line spectrum in **Figure 8** has been used to predict some of the electron energy levels in a hydrogen atom.

The energy levels predicted from the visible line spectrum are those between 0 and –3.40 eV in the energy level diagram.

Some of the predicted energy levels are shown in **Figure 9**.

Figure 9



1.1 Calculate the energy, in eV, of a photon of light that has the lowest frequency in the visible hydrogen spectrum shown in **Figure 8.**

[3 marks]

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Energy of photon = ... eV

1.2 Identify the state of an electron in the energy level labelled 0.

[1 mark]

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1.3 Identify the state of an electron that is in the energy level labelled –13.6 eV.

[1 mark]

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1.4 Explain why the energy levels are negative.

[1 mark]

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1.5 Discuss how the discharge tube is made to emit electromagnetic radiation of specific frequencies.

In your answer you should:

• Explain why there must be a high potential difference across the tube

• Discuss how the energy level diagram in **Figure 9** predicts the spectrum shown in **Figure 8**

• Show how one of the wavelengths of light is related to two of the energy levels in the energy level diagram.

[6 marks]

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Reference: AQA AS Physics Paper 1 Examination June 2017

MARK SCHEME

1.1	$\lambda = 656$ nm ✓ Use of $E = hc/\lambda$ ✓ $= 3.0 \times 10^{-19}$ (J) $E/ 1.6 \times 10^{-19}$ = 1.9 (1.88) (allow 1sf if correct)	Power of 10 error allow 2 Allow ecf for wrong choice of wavelength Treat as skill mark – allow conversion for any value of E	3
1.2	They are (just) free ✓	Allow released from atom	1
1.3	This is the ground state ✓ or This is the lowest level an electron can occupy	Allow lowest energy state Condone level for state Allow description of ground state	1

1.4	To become free/to remove an electron (reach zero energy) energy has to be supplied ✓ or Energy decreases from 0 as electrons move to lower energy levels/relate to energy needed to move from that state to 0	Or Electrons release energy as they move lower Or Zero is the maximum energy	1

1.5	**The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question** Mark – Criteria 6 – All three aspects analysed. 6 marks can be awarded even if there is an error and/or parts of one aspect missing. 5 – A fair attempt to analyse all 3 aspects. If there are a couple of errors or missing parts then 5 marks should be awarded. 4 – Two aspects successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error. 3 – Two aspects discussed, or one discussed and two others covered partially. There are likely to be several errors and omissions in the discussion. 2 – Only one aspect discussed successfully, or makes a partial attempt at 2 or all 3. 1 – None of the three aspects covered without significant error. 0 – No relevant analysis.	The following statements are likely to be present. **A Reason for high potential difference** pd accelerates electrons/produces high speed/high energy electrons in the tube L1 electrons have to have sufficient energy to excite the atoms/raise electrons into higher levels L3 **B Relation between spectrum and energy level diagram** Visible spectrum results from excited electrons moving into the lower level at -3.4 eV L3 Each transition results in a photon of light L2 Energy of photon is the difference in the energies of the two levels L2 Frequency of light in the spectrum given by $\Delta E = hf$ L1 **C Relevant calculation clearly communicated** Gives an example: eg the lowest frequency is due to a transition from the -1.5 eV level to the -3.4 level. L1 Uses an energy difference to deduce one of the wavelengths: eg energy difference in J = 3×10^{-19} L2 $\lambda = hc/E = 660$ nm L2	6

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

A4. Do you need to carry out further revision on this topic?

Revision Target

From this question, are there any targets you need to set for revision? What are they?

QUESTION TWO

7 In 1905 Einstein presented a theory to explain the photoelectric effect using the concept of quantisation of radiation proposed by Planck in 1900.

(a) Show, with the aid of a suitably labelled diagram, the arrangement of apparatus that could be used to demonstrate the photoelectric effect. Describe how you would use the apparatus and what would be observed.

In your answer you should make clear how your observations provide evidence for the photoelectric effect.

[5]

(b) Describe how the photoelectric effect can be explained in terms of the physics of quantum behaviour.

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.... **[5]**

[Total: 10]

Reference: OCR Physics Unit 2 June 2009 Examination

MARK SCHEME

Question			Expected Answers	Marks	Additional Guidance
7	a		A (clean) zinc plate mounted on the cap of a gold-leaf electroscope. Plate initially charged negatively A u-v lamp shining on plate The gold leaf collapses as the charge leaks away from the plate (when ultra-violet light is incident on the zinc plate) so experiment indicates the emission of negative charge/electrons	B1 B1 B1 B1 B1	first 3 marks can be awarded from diagram or description QWC mark
		Or	A simple photocell, eg two plates in a vacuum envelope A (12 V) dc supply is connected to the photocell and (nano)ammeter. A suitable frequency/u-v lamp shining on one plate The presence of u-v /blue light causes a current in the circuit. so experiment indicates the emission of negative charge/electrons	B1 B1 B1 B1 B1	**accept** photocell made of clean magnesium ribbon surrounded by fine copper gauze first 3 marks can be awarded from diagram or description **ignore** polarity of supply QWC mark
		Or	A (potassium) photocell connected across a (high impedance) voltmeter. Incident light of different frequencies; produced either by white light source and colour filters of known spectral range or by using a diffraction grating or prism to produce a first order spectrum. Different p.d.s are set up across the electrodes of the photocell (when the photocathode is illuminated with light of different frequencies). so experiment indicates the emission of negative charge	B1 B1 B1 B1 B1	first 3 marks can be awarded from diagram or description QWC mark
	b		Individual photons are absorbed by individual electrons in the metal surface. These electrons must have absorbed sufficient energy to overcome the work function energy of the metal/to reach the minimum energy to release an electron from the surface **or** only photons with energies above the work function energy will cause photoelectron emission Concept of instantaneous emission Number of electrons emitted also depends on light intensity Einstein's photoelectric energy equation in symbols with symbols explained, ie (energy of photon) = (work function of metal) + (maximum possible kinetic energy of emitted electron)	B1 B1 B1 B1 B1 B1	**stop marking after the first five marking points, ie ticks and crosses** **not** photons are absorbed by electrons; 1 to 1 relationship must be implied **accept** definition of work function energy **accept** shorter λ/higher f photon causes higher (kinetic) energy electron **accept** full word equation without symbols for 2 marks maximum 5 marks
			Total question 7	**10**	

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

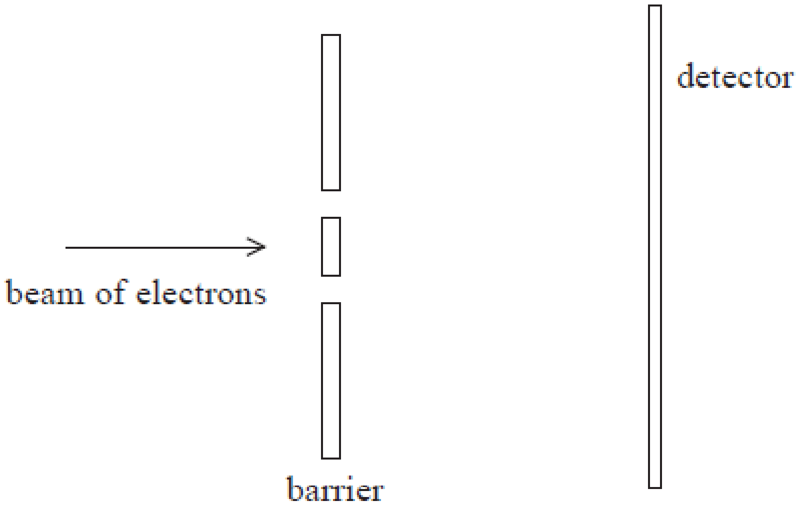
A4. Do you need to carry out further revision on this topic?

Revision Target

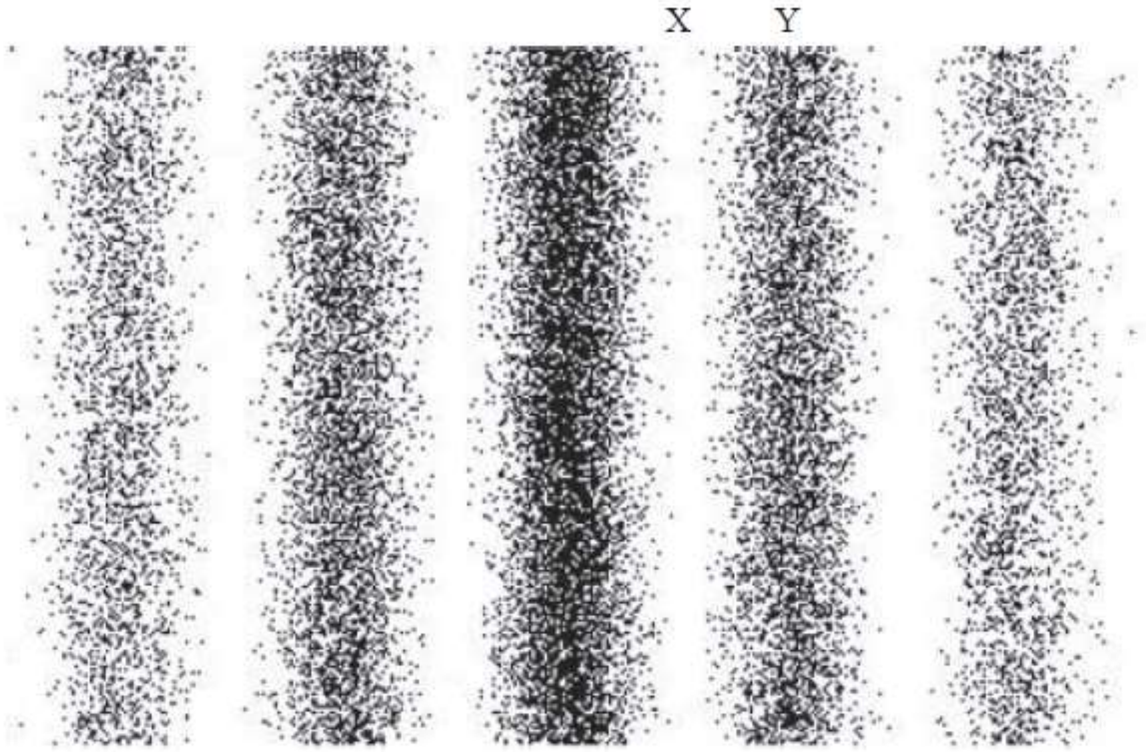
From this question, are there any targets you need to set for revision? What are they?

QUESTION THREE

In 1965, Richard Feynman proposed a double slit experiment to investigate the wave properties of electrons.



The experiment was later carried out using the arrangement shown.
A beam of electrons was directed at a barrier with two slits.
The detector recorded the positions where electrons arrived after passing through the slits.
The following pattern was obtained. Black dots represent points where electrons were detected.
A band where electrons were not detected has been labelled **X** and a band where electrons were detected has been labelled **Y**.



The path difference for electrons arriving at band **X** from the separate slits was 2.5×10^{-11}m.
For electrons arriving at band **Y** the path difference was 5.0×10^{-11} m.
Explain why this pattern is observed when the electron energy is 9.6×10^{-17}J.
The electrons are travelling at non-relativistic speeds.

[6 Marks]

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Reference: EdExcel A Level Physics Paper 2 June 2018 Examination

MARK SCHEME

Question Number	Acceptable answers		Additional guidance	Mark
3	• Use of $E_K = p^2 / 2m$	(1)	MP1 accept use of $p = mv$ and Use of $E_k = ½ mv^2$ MP4 accept (n + ½) λ or n λ respectively <u>Example of calculation</u> $p = \sqrt{(2 \times 9.11 \times 10^{-31} \text{ kg} \times 9.6 \times 10^{-17} \text{ J})}$ $p = 1.32 \times 10^{-23}$ kg m s^{-1} $\lambda = 6.63 \times 10^{-34}$ Js / 1.32×10^{-23} kg m s^{-1} $\lambda = 5.0 \times 10^{-11}$ m	6
	• Use of $\lambda = h/p$	(1)		
	• $\lambda = 5.0 \times 10^{-11}$ (m) calculated from E_K **Or** $E_K = 9.7 \times 10^{-17}$ (J) calculated from $\lambda = 5.0 \times 10^{-11}$ m **Or** $p = 1.3 \times 10^{-23}$ (kg m s^{-1}) calculated from E_K **and** $p = 1.3 \times 10^{-23}$ (kg m s^{-1}) calculated from $\lambda = 5.0 \times 10^{-11}$ m	(1)		
	• path difference at X is $\lambda/2$ **Or** path difference at Y is λ	(1)		
	• (electron) <u>waves</u> at X are in antiphase **Or** (electron) <u>waves</u> at Y are in phase	(1)		
	• at X destructive interference/superposition takes place **Or** at Y constructive interference/superposition takes place	(1)		

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

A4. Do you need to carry out further revision on this topic?

Revision Target

From this question, are there any targets you need to set for revision? What are they?

QUESTION FOUR

4. A coulombmeter is used to measure charge.

In a laboratory demonstration of the photoelectric effect, a sheet of zinc was placed on top of a coulombmeter and the zinc was given a negative charge.

4.1 The following observations were made:

• Under normal lighting conditions the charge remained constant

• When the zinc was illuminated with ultraviolet light, the magnitude of the charge on the zinc decreased as time passed

• When a larger sheet of zinc was used the charge on the zinc decreased more rapidly.

In each case the initial charge on the zinc was the same.

Explain these observations.

[6 Marks]

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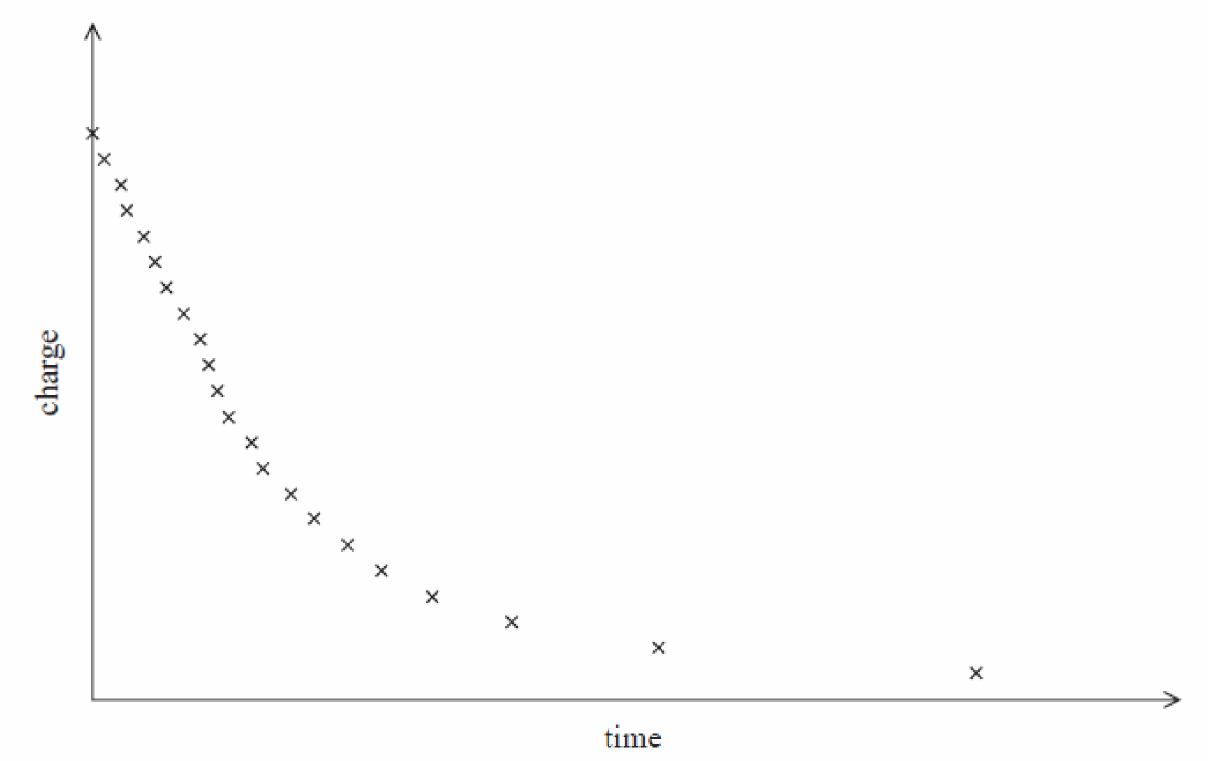
4.2 For one sheet of zinc, the charge at different times was measured.

The following graph was obtained.



A student suggests that this is an exponential decay curve.

Explain how this suggestion could be tested.

[3 Marks]

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Reference: EdExcel A Level Physics Paper 2 June 2017 Examination

MARK SCHEME

4.1

This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Indicative content

- photon energy $E = hf$
- photon energy must be greater than work function (of metal) for photon to provide enough energy for photoemission
- UV photons have sufficient energy for photoemission but lab light photons do not
- one photon interacts with one electron
- with larger area more photons are absorbed/incident in a given time
- more electrons are emitted in a given time (so the charge is lost more quickly)

The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure and lines of reasoning
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkage between points and is unstructured	0

IC2 accept answers in terms of threshold frequency
IC5 & 6 there must be the idea of 'rate' once

Number of IC points awarded	Possible linkage marks
0,1	0
2, 3	1
4, 5, 6	2

6

4.2

- would be of form $Q = Q_0 e^{-kt}$ (1)
- plot ln charge against time (1)
- if straight line with negative gradient it's exponential (1)

Or

- would be of form $Q = Q_0 e^{-kt}$ (1)
- Calculate Q/Q_0 for pairs of values with same time interval t **Or** calculates $t_{1/2}$ at least twice (1)
- If equal, then it's exponential (1)

MP3 accept some indication that gradient is negative

For both MS options MP3 is dependent on MP2

3

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

A4. Do you need to carry out further revision on this topic?

Revision Target

From this question, are there any targets you need to set for revision? What are they?

QUESTION FIVE

5. Helium was discovered in the 1860s by observing the spectrum produced by sunlight. An intense spectral line was seen, which did not correspond with any elements known at the time.

Explain how specific spectral lines are produced by a hot gas.

[6 Marks]

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Reference: EdExcel International A Level Physics Paper 2 January 2019 Examination

MARK SCHEME

Question Number	Answer		Mark
5	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)		
	There are discrete energy levels **Or** only specific energy levels are possible	(1)	
	Atoms/electrons (gain energy and) move to higher energy levels **Or** Atoms/electrons (gain energy and) get excited	(1)	
	Atoms/electrons then move to lower energy levels (accept ground state) and a photon is emitted **Or** Atoms/electrons are de-excited and a photon is emitted	(1)	
	The energy of a photon if proportional to its frequency (Accept $E = hf$ with E and f defined)	(1)	
	The energy of the photon is equal to the difference in energy levels	(1)	
	There are specific frequencies emitted because the energy differences are specific	(1)	**6**
	(accept answers in terms of wavelength)		
	Total for question 13		**6**

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

A4. Do you need to carry out further revision on this topic?

Revision Target

From this question, are there any targets you need to set for revision? What are they?

QUESTION SIX

9 A proton travelling at a high velocity is fired at a stationary proton. It stops momentarily at a distance of 2.0×10^{-15} m from the stationary proton.

(a) Calculate the electrostatic force acting on each proton when separated by 2.0×10^{-15} m.

force = ... N **[2]**

(b) The two protons fuse together. Explain how the protons are able to remain together.

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.... **[1]**

(c) Explain why the proton must have a very large velocity for the fusion to occur and the protons to remain together.

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.... **[2]**

[Total: 5]

Reference: OCR Physics Unit 5 June 2010 Examination

MARK SCHEME

Question			Expected Answers	Marks	Additional Guidance
9	a		$F = Q_1Q_2 / 4\pi\varepsilon_0 r^2$ $= (1.6 \times 10^{-19} \times 1.6 \times 10^{-19}) / 4\pi\varepsilon_0 (2\times 10^{-15})^2$ = 57.5 (N)	C1 A1	Allow use of 9×10^9 instead of $1 / 4\pi\varepsilon_0$ (using this gives 57.6) Allow ≥ 2sf (58) If correct formula quoted and then AE (e.g. not squaring r <u>or</u> not squaring Q) then allow ecf in final answer for 2/3
	b		<u>attractive</u> strong (nuclear force)	B1	Do not it holds them together
	c		as the proton travels towards the stationary proton it experiences a repulsive force that slows it down. (It needs a high velocity) to get close enough (to the proton) / for the (attractive) <u>short range</u> force to have any effect	B1 B1	
			Total	**[5]**	

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

A4. Do you need to carry out further revision on this topic?

Revision Target

From this question, are there any targets you need to set for revision? What are they?

QUESTION SEVEN

9 (a) (i) Complete Fig. 9.1 to show the quark composition and charge for neutrons and protons.

	quark composition	charge
neutron		
proton		

Fig. 9.1

[2]

(ii) Complete Fig. 9.2 to show the composition of quarks.

quark	charge	baryon number	strangeness
up		+ 1/3	
down			0

Fig. 9.2

[2]

(b) When a neutron decays it can produce particles that include an electron.

(i) Complete the decay equation below for a neutron.

$^{1}_{0}n \longrightarrow$

[2]

(ii) Name the interaction responsible for the decay of the neutron.

.... **[1]**

(iii) Electrons and neutrons belong to different groups of particles. Name the group of particles to which each belongs.

electrons ....

neutrons .... **[1]**

Reference: OCR Physics Unit 5 January 2011 Examination

MARK SCHEME

Question			Expected Answer	Mark	Additional Guidance
9	(a)	(i)	composition for n and p: u d d & u u d	B1	
			charge for n and p: 0 & +1	B1	**Allow**: charge 'e' instead of '+1' or '1'
		(ii)	up +2/3 **(+1/3)** 0	B1	**Allow**: charges in terms of 'e'
			down -1/3 +1/3 **(0)**	B1	
	(b)	(i)	${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{\nu}$	A2	**Allow**: '→ proton + electron + antineutrino' **Note**: -1 for any omission or error. Score = 0 if more than one error
		(ii)	weak (nuclear)	B1	
		(iii)	lepton(s) and hadron(s) / baryons(s)	B1	**Not**: Neutrons are mesons
			Total	8	

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

A4. Do you need to carry out further revision on this topic?

Revision Target

From this question, are there any targets you need to set for revision? What are they?

QUESTION EIGHT

(a) An electron is an example of a *lepton* and a proton is an example of a *hadron*.
State a property of a hadron.

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.... **[1]**

(b) State the charge, in terms of the elementary charge *e*, on an up quark and a down quark.

charge on up quark = ... *e*   charge on down quark = ... *e*   **[1]**

(c) The quark composition of a neutron is u d d.
State the quark composition of a proton.

.... **[1]**

(d) In large particle accelerators, short-lived particles called pions are created by colliding high-speed protons (p) with stationary neutrons (n). The equation below shows a reaction in which a negative pion (π^-) is produced.

$$p + n \rightarrow p + p + \pi^-$$

The π^- particle consists of a quark and an anti-quark.
Use the information provided about the neutron and your answer to **(c)** to write an equation for the reaction in terms of up (u) and down (d) quarks. Hence determine the quark composition of the π^- particle.

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.... **[3]**

(e) (i) State Einstein's mass-energy equation and define all the terms.

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.... [1]

(ii) In the reaction

$$p + n \rightarrow p + p + \pi^-$$

the π^- particle is produced when the proton colliding with a stationary neutron has a minimum kinetic energy of 1.4×10^8 eV. The mass of a proton and a neutron may be assumed to be the same.
Calculate the mass of the π^- particle.

mass = ... kg [2]

Reference: OCR Physics Unit 5 2016 Examination

MARK SCHEME

Question			Answers	Marks	Guidance
6	(a)		Hadrons are made of quarks / they experience the strong (nuclear) force / interaction	B1	**Not** 'they are baryons' **Allow** 'held together by gluons' (AW) **Ignore** the number of quarks mentioned
	(b)		$\frac{2}{3}$ (e); $-\frac{1}{3}$ (e)	B1	**Allow** 0.67 (e) and – 0.33 (e)
	(c)		(proton =) u u d	B1	**Allow** up up down
	(d)		($p + n \rightarrow p + p + \pi^-$) u u d + u d d → u u d + u u d + π^- (left-hand side = d and right-hand side = u + π^-) π^- has one down quark or π^- has d and one anti-up quark or π^- has $\bar{u}$	 C1 A1 A1	**Allow** other correct methods **Note:** This mark is for *substitution* **Note**: Any more than 2 quarks does not score the A1 marks **Allow** 3 marks for d $\bar{u}$
	(e)	(i)	$\Delta E = \Delta m\, c^2$ where ΔE is (change in) energy, Δm is (change in) mass and c is speed of light (in a vacuum)	B1	**Allow** energy = mass × speed of light^2 **Not** binding energy = mass defect × speed of light^2 **Not** energy = mass defect × speed of light^2
	(e)	(ii)	(KE =) $1.4 \times 10^8 \times 1.6 \times 10^{-19}$ or 2.24×10^{-11} (J) (mass of π^- =) $\frac{2.24\times10^{-11}}{(3.0\times10^8)^2}$ mass = 2.5×10^{-28} (kg)	C1 A1	
			Total	**9**	

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

A4. Do you need to carry out further revision on this topic?

Revision Target

From this question, are there any targets you need to set for revision? What are they?

QUESTION NINE

(a) State, with a reason, whether or not protons and neutrons are fundamental particles.

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.... **[1]**

(b) State **two** fundamental particles that can be classified as leptons.

.... **[1]**

(c) Some fruits, such as bananas, are naturally radioactive because they contain the unstable isotope of potassium-40 ($^{40}_{19}K$).

(i) The isotope of potassium-40 is a beta-minus emitter.

Complete the following decay equation for $^{40}_{19}K$.

$$^{40}_{19}K \rightarrow \,^{\dots\dots}_{\dots\dots}Ca + \dots\dots\dots + \dots\dots\dots$$ **[2]**

(ii) Explain why energy is released when a single nucleus of potassium-40 decays.

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(iii) A banana contains 4.5×10^{-4} kg of potassium. About 0.012% of the mass of potassium in the banana has the unstable isotope of potassium-40. This isotope of potassium-40 has a half-life of 4.2×10^{16} s. The molar mass of potassium-40 is 0.040 kg mol^{-1}.

Calculate the activity from this banana.

activity = ... Bq **[3]**

Reference: OCR Physics Unit 5 2015 Examination

MARK SCHEME

Question			Answer	Marks	Guidance
3	(a)		They are not fundamental particles because they consist of quarks	B1	**Not**: They can be sub-divided
	(b)		Any two from: electron / positron / neutrino / antineutrino	B1	**Allow**: muon / tau
	(c)	(i)	$^{40}_{20}\text{Ca}$ $^{0}_{-1}e + \bar{\nu}_{(e)}$ or electron + (electron) antineutrino	B1 B1	 **Allow**: $^{0}_{-1}\beta$ but not β^- or e^- for the electron
		(ii)	There is a decrease in mass Energy (released) given by $(\Delta)E = (\Delta)mc^2$ **or** Binding energy increases Energy (released) is the difference between the binding energies (of Ca and K nuclei)	M1 A1 M1 A1	 **Ignore** Δm being referred to as the 'mass defect' **Allow**: binding energy per nucleon increases
		(iii)	$\lambda = \dfrac{0.693}{4.2 \times 10^{16}}$ / $N = \dfrac{0.012}{100} \times \dfrac{4.5 \times 10^{-4}}{0.040} \times 6.02 \times 10^{23}$ $A = 1.65 \times 10^{-17} \times 8.127 \times 10^{17}$ activity = 13 (Bq)	C1 C1 A1	**Allow**: 1 mark for either $\lambda = 1.65 \times 10^{-17}$ s^{-1} or $N = 8.127 \times 10^{17}$ **Note**: Answer to 3 sf is 13.4 (Bq) **Note**: 1.3×10^3 (Bq) scores 2 marks; division by 100 omitted
			Total	9	

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

A4. Do you need to carry out further revision on this topic?

Revision Target

From this question, are there any targets you need to set for revision? What are they?

QUESTION TEN

In an experiment it is observed that when blue light is shone on a clean metal surface electrons are emitted, but with red light there is no electron emission.

(a) State the name of the effect observed in this experiment.

.... **[1]**

(b) Describe Einstein's theory to explain these observations.

In your answer you should include technical terms to explain how the physics of quantum behaviour is used to explain the observations.

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.... **[4]**

(c) The longest wavelength of light incident on the metal surface which causes electrons to be emitted is 480 nm.

(i) Show that the work function of the metal is about 4×10^{-19} J.

[3]

(ii) Calculate the maximum speed of an emitted electron when a photon of energy 5.2×10^{-19} J is incident on the metal surface.

speed = ... $m\,s^{-1}$ [3]

(d) (i) Describe briefly one piece of evidence for believing that electrons sometimes behave like waves.

....

....

....

.... [2]

(ii) Calculate the de Broglie wavelength of an electron moving at $500\,km\,s^{-1}$.

wavelength = ... m [3]

MARK SCHEME

Question			Answer	M	Guidance
6					
	a		photoelectric effect	B1	
	b		**1.**Individual photons are absorbed by individual electrons (in the metal surface)/ one to one interaction/AW **2.**Only photon with energy above the work function energy will cause photoelectron emission/idea of threshold frequency **3.**Photon energy is proportional to frequency **4.**(therefore) blue photons with higher f/shorter λ will cause photoemission but red photons will not. **5.**$hf - \phi = KE_{max}$ is the equation resulting from conservation of energy **or** resulting from the meaning of each term **6.**A wave model does not explain instantaneous emission	B1 B1 B1 B1 B1 B1	**max** 4 from 6 marking points **allow** work function (of a metal surface) is minimum energy for photoemission **allow** shorter wavelength light has higher energy (hc/λ) or higher frequency higher energy (hf) **or** ….red photons with lower f/longer λ….. *max* must be present to score mark; equation stated in words: photon e. – w.f. = max ke of *e* to score full marks (4) the answer **must include** two terms out of *photon, work function* and *threshold frequency/wavelength* (QWC mark)
	c	i	work function = $\phi = hc/\lambda$ $\varphi = 6.6 \times 10^{-34} \times 3.0 \times 10^{8} / 4.8 \times 10^{-7}$ $= 4.1(4) \times 10^{-19}$ (J)	C1 M1 A1	allow $\phi = hf$ ($f = 6.25 \times 10^{14}$) and $f = c/\lambda$ must show answer <u>initially</u> to 2 or 3 SF; ignore any <u>final</u> rounding down to 1 SF
		ii	$E - \phi = \frac{1}{2}mv^2$ $(5.2 - 4.1) \times 10^{-19} = 1.1 \times 10^{-19} = \frac{1}{2}mv^2$ $v = \sqrt{(2 \times 1.1 \times 10^{-19} / 9.1 \times 10^{-31})}$ $v = 4.9 \times 10^{5}$ (m s^{-1})	C1 C1 A1	can use 4.14 or 4 instead of 4.1 **allow** 5.1×10^{5} (m s^{-1}) using $\phi = 4 \times 10^{-19}$ or 4.8×10^{5} (m s^{-1}) using $\phi = 4.14 \times 10^{-19}$
	d	i	electrons passing through a thin sheet of graphite are diffracted/produce diffraction rings on a fluorescent screen	M1 A1	any suitable/reasonably plausible situation what is observed/ interpretation
		ii	$\lambda = h/mv$ $\lambda = 6.63 \times 10^{-34} / 5.0 \times 10^{5} \times 9.1 \times 10^{-31}$ $\lambda = 1.5 \times 10^{-9}$ (m)	C1 C1 A1	1.46 to 3 SF
			Total question 6	**16**	

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

A4. Do you need to carry out further revision on this topic?

Revision Target

From this question, are there any targets you need to set for revision? What are they?

QUESTION ELEVEN

A photoelectric cell is an electronic device that can detect photons.

(a) Fig. 4.1 shows a cross-section through a simple photocell.

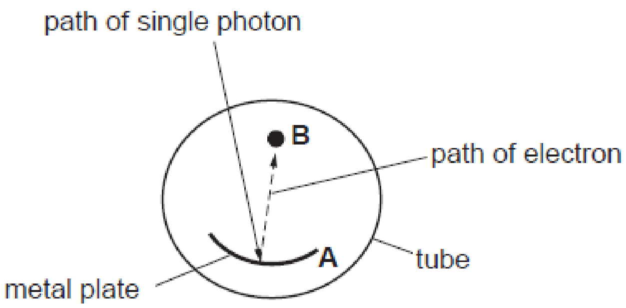

Fig. 4.1

A metal plate **A** is coated with potassium in an evacuated transparent tube. A photon entering the tube is absorbed by the plate, causing one electron to be released from the surface towards the collector rod **B**.

(i) State the name of this process.

.... **[1]**

(ii) Potassium has a work function of 3.5×10^{-19} J.

1 Define the term *work function*.

....

.... **[1]**

2 Calculate the threshold frequency of potassium.

threshold frequency = ... Hz **[2]**

(iii) The photon incident on plate **A** has a wavelength of 4.2×10^{-7} m. Show that its energy is about 5×10^{-19} J.

[2]

(iv) Calculate the maximum kinetic energy of the electron emitted from the potassium surface of plate **A**.

maximum kinetic energy = ... J **[2]**

(b) An electron is released with zero speed from plate **A**. It is accelerated from plate **A** through a potential difference of 12 V to the metal rod **B** in Fig. 4.1.

(i) **1** State the increase in kinetic energy of the electron in electronvolts (eV).

increase in k.e. = ... eV **[1]**

2 Show that this increase is about 2×10^{-18} J.

[1]

(ii) Calculate the speed of the electron as it hits rod **B**.

speed = ... $m\,s^{-1}$ **[3]**

(c) The photocell is connected to a 12 V d.c. supply through a very sensitive ammeter. Light of wavelength 4.2×10^{-7} m shines on plate **A**. The plate absorbs 1.2×10^{-6} J of light energy every second. One per cent of the absorbed photons cause electrons to be emitted from the plate. Estimate the current in the circuit.

current = ... A **[3]**

Reference: OCR Physics Unit 2 June 2011 Examination

MARK SCHEME

Question			Expected Answers	M	Additional Guidance
4					
	a	i	photoelectric effect/emission	B1	
		ii1 ii2	the <u>minimum</u> energy (required) to release an electron (from the surface of the metal) $3.5 \times 10^{-19} = 6.6 \times 10^{-34}$ f f = 5.3×10^{14} (Hz)	B1 C1 A1	
		iii	$\varepsilon = hc/\lambda = 6.6 \times 10^{-34} \times 3.0 \times 10^{8} / 4.2 \times 10^{-7}$ $= 4.7 \times 10^{-19}$ (J)	C1 A1	no second mark unless there is evidence of the calculation being done
		iv	$\frac{1}{2}mv^2 = 4.7 \times 10^{-19} - 3.5 \times 10^{-19}$ $= 1.2 \times 10^{-19}$ (J)	C1 A1	mark for using the p.e. equation **accept** 1.5×10^{-19} from those using 5×10^{-19} J
	b	i1 ii2	12 (eV) $\varepsilon = eV = 12 \times 1.6 \times 10^{-19} = 1.92 \times 10^{-18}$ (J)	B1 A1	 **ecf(b)(i)1**
		ii	$\frac{1}{2}mv^2 = 2.0 \times 10^{-18}$ $v^2 = 2 \times 2.0 \times 10^{-18}/9.1 \times 10^{-31} = 4.4 \times 10^{12}$ $v = 2.1 \times 10^{6}$ (m s^{-1})	C1 C1 A1	$\frac{1}{2}mv^2 = 12$ scores 0/3 **accept** 1.9×10^{-18} from **(b)(i)2** giving $v = 2.0(5) \times 10^{6}$
	c		e's emitted/s = $1.2 \times 10^{-8}/5 \times 10^{-19} = 2.4 \times 10^{10}$ current = $2.4 \times 10^{10} \times 1.6 \times 10^{-19}$ $= 3.8 \times 10^{-9}$ (A) to 4.1×10^{-9} (A)	C1 C1 A1	using 4.7×10^{-19} gives 2.55×10^{10} omitting 1% scores as a POT error allow 4 nA as the question states 'estimate'
			Total question 4	**16**	

Revision Reflection

A1. Could you answer this question without any help?

A2. Could you answer this question correctly?

A3. Did you encounter any problems with this question?

A4. Do you need to carry out further revision on this topic?

Revision Target

From this question, are there any targets you need to set for revision? What are they?

DATASHEET

DATA - FUNDAMENTAL CONSTANTS AND VALUES

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^{8}	$\mathrm{m\,s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\,m^{-1}}$
permittivity of free space	ε_0	8.85×10^{-12}	$\mathrm{F\,m^{-1}}$
magnitude of the charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\mathrm{N\,m^{2}\,kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\,K^{-1}\,mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\,K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\,m^{-2}\,K^{-4}}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	$\frac{e}{m_e}$	1.76×10^{11}	$\mathrm{C\,kg^{-1}}$
proton rest mass (equivalent to 1.00728 u)	m_p	$1.67(3) \times 10^{-27}$	kg
proton charge/mass ratio	$\frac{e}{m_p}$	9.58×10^{7}	$\mathrm{C\,kg^{-1}}$
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	$\mathrm{N\,kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\,s^{-2}}$
atomic mass unit (1u is equivalent to 931.5 MeV)	u	1.661×10^{-27}	kg

ALGEBRAIC EQUATION

quadratic equation $$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

ASTRONOMICAL DATA

Body	Mass/kg	Mean radius/m
Sun	1.99×10^{30}	6.96×10^{8}
Earth	5.97×10^{24}	6.37×10^{6}

GEOMETRICAL EQUATIONS

arc length	$= r\theta$
circumference of circle	$= 2\pi r$
area of circle	$= \pi r^2$
curved surface area of cylinder	$= 2\pi rh$
area of sphere	$= 4\pi r^2$
volume of sphere	$= \frac{4}{3}\pi r^3$

Particle Physics

Class	Name	Symbol	Rest energy/MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	π meson	$\pi^\pm$	139.576
		π^0	134.972
	K meson	$K^\pm$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

antiquarks have opposite signs

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of Leptons

		Lepton number
Particles:	e^-, ν_e ; μ^-, ν_μ	$+1$
Antiparticles:	e^+, $\overline{\nu_e}$, μ^+, $\overline{\nu_\mu}$	-1

Photons and energy levels

photon energy $E = hf = hc/\lambda$

photoelectricity $hf = \phi + E_{k\,(max)}$

energy levels $hf = E_1 - E_2$

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

Waves

wave speed $c = f\lambda$ *period* $f = \frac{1}{T}$

first harmonic $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

fringe spacing $w = \frac{\lambda D}{s}$ *diffraction grating* $d\sin\theta = n\lambda$

refractive index of a substance s, $n = \frac{c}{c_s}$

for two different substances of refractive indices n_1 *and* n_2,

law of refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$

critical angle $\sin\theta_c = \frac{n_2}{n_1}$ for $n_1 > n_2$

Mechanics

moments moment $= Fd$

velocity and acceleration $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$

equations of motion $v = u + at$ $s = \left(\frac{u+v}{2}\right)t$

$v^2 = u^2 + 2as$ $s = ut + \frac{at^2}{2}$

force $F = ma$

force $F = \frac{\Delta(mv)}{\Delta t}$

impulse $F\Delta t = \Delta(mv)$

work, energy and power $W = Fs\cos\theta$

$E_k = \frac{1}{2}mv^2$ $\Delta E_p = mg\Delta h$

$P = \frac{\Delta W}{\Delta t}$, $P = Fv$

$efficiency = \frac{useful\ output\ power}{input\ power}$

Materials

density $\rho = \frac{m}{V}$ *Hooke's law* $F = k\,\Delta L$

Young modulus $= \frac{tensile\ stress}{tensile\ strain}$ *tensile stress* $= \frac{F}{A}$ *tensile strain* $= \frac{\Delta L}{L}$

energy stored $E = \frac{1}{2}F\Delta L$

Electricity

current and pd	$I = \frac{\Delta Q}{\Delta t}$ $V = \frac{W}{Q}$ $R = \frac{V}{I}$
resistivity	$\rho = \frac{RA}{L}$
resistors in series	$R_T = R_1 + R_2 + R_3 + \ldots$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$
power	$P = VI = I^2R = \frac{V^2}{R}$
emf	$\varepsilon = \frac{E}{Q}$ $\varepsilon = I(R + r)$

Circular motion

magnitude of angular speed	$\omega = \frac{v}{r}$
	$\omega = 2\pi f$
centripetal acceleration	$a = \frac{v^2}{r} = \omega^2 r$
centripetal force	$F = \frac{mv^2}{r} = m\omega^2 r$

Simple harmonic motion

acceleration	$a = -\omega^2 x$
displacement	$x = A\cos(\omega t)$
speed	$v = \pm\omega\sqrt{(A^2 - x^2)}$
maximum speed	$v_{max} = \omega A$
maximum acceleration	$a_{max} = \omega^2 A$
for a mass-spring system	$T = 2\pi\sqrt{\frac{m}{k}}$
for a simple pendulum	$T = 2\pi\sqrt{\frac{l}{g}}$

Thermal physics

energy to change temperature	$Q = mc\Delta\theta$
energy to change state	$Q = ml$
gas law	$pV = nRT$
	$pV = NkT$
kinetic theory model	$pV = \frac{1}{3}Nm(c_{rms})^2$
kinetic energy of gas molecule	$\frac{1}{2}m(c_{rms})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$

Gravitational fields

force between two masses	$F = \frac{Gm_1m_2}{r^2}$
gravitational field strength	$g = \frac{F}{m}$
magnitude of gravitational field strength in a radial field	$g = \frac{GM}{r^2}$
work done	$\Delta W = m\Delta V$
gravitational potential	$V = -\frac{GM}{r}$
	$g = -\frac{\Delta V}{\Delta r}$

Electric fields and capacitors

force between two point charges	$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$
force on a charge	$F = EQ$
field strength for a uniform field	$E = \frac{V}{d}$
work done	$\Delta W = Q\Delta V$
field strength for a radial field	$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$
electric potential	$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$
	$E = \frac{\Delta V}{\Delta r}$
capacitance	$C = \frac{Q}{V}$
	$C = \frac{A\varepsilon_0\varepsilon_r}{d}$
capacitor energy stored	$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$
capacitor charging	$Q = Q_0(1 - e^{-t/RC})$
decay of charge	$Q = Q_0 e^{-t/RC}$
time constant	RC

Magnetic fields

force on a current $F = BIl$

force on a moving charge $F = BQv$

magnetic flux $\Phi = BA$

magnetic flux linkage $N\Phi = BAN\cos\theta$

magnitude of induced emf $\varepsilon = N\frac{\Delta\Phi}{\Delta t}$

$N\Phi = BAN\cos\theta$

emf induced in a rotating coil $\varepsilon = BAN\omega\sin\omega t$

alternating current $I_{rms} = \frac{I_0}{\sqrt{2}}$ $V_{rms} = \frac{V_0}{\sqrt{2}}$

transformer equations $\frac{N_s}{N_p} = \frac{V_s}{V_p}$

$efficiency = \frac{I_s V_s}{I_p V_p}$

Nuclear physics

the inverse square law for γ radiation $I = \frac{k}{x^2}$

radioactive decay $\frac{\Delta N}{\Delta t} = -\lambda N$, $N = N_0 e^{-\lambda t}$

activity $A = \lambda N$

half-life $T_{½} = \frac{\ln 2}{\lambda}$

nuclear radius $R = R_0 A^{1/3}$

energy-mass equation $E = mc^2$

OPTIONS

Astrophysics

1 astronomical unit = 1.50×10^{11} m

1 light year = 9.46×10^{15} m

1 parsec = 206265 AU = 3.08×10^{16} m
= 3.26 light year

Hubble constant, $H = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$

$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$

in normal adjustment $M = \frac{f_0}{f_e}$

Rayleigh criterion $\theta \approx \frac{\lambda}{D}$

magnitude equation $m - M = 5\log\frac{d}{10}$

Wien's law $\lambda_{max} T = 2.9 \times 10^{-3}$ m K

Stefan's law $P = \sigma A T^4$

Schwarzschild radius $R_s \approx \frac{2GM}{c^2}$

Doppler shift for v << c $\frac{\Delta f}{f} = -\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$

red shift $z = -\frac{v}{c}$

Hubble's law $v = Hd$

Medical physics

lens equations $P = \frac{1}{f}$

$m = \frac{v}{u}$

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

threshold of hearing $I_0 = 1.0 \times 10^{-12} \text{ W m}^{-2}$

intensity level $intensity\ level = 10\log\frac{I}{I_0}$

absorption $I = I_0 e^{-\mu x}$

$\mu_m = \frac{\mu}{\rho}$

ultrasound imaging $Z = \rho c$

$\frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$

half-lives $\frac{1}{T_E} = \frac{1}{T_B} + \frac{1}{T_P}$

Engineering physics

moment of inertia $I = \Sigma mr^2$

angular kinetic energy $E_k = \frac{1}{2}I\omega^2$

equations of angular motion

$\omega_2 = \omega_1 + \alpha t$

$\omega_2{}^2 = \omega_1{}^2 + 2\alpha\theta$

$\theta = \omega_1 t + \frac{\alpha t^2}{2}$

$\theta = \frac{(\omega_1 + \omega_2)\,t}{2}$

torque $T = I\,\alpha$

$T = F\,r$

angular momentum angular momentum $= I\omega$

angular impulse $T\Delta t = \Delta(I\omega)$

work done $W = T\theta$

power $P = T\omega$

thermodynamics $Q = \Delta U + W$

$W = p\Delta V$

adiabatic change $pV^\gamma =$ constant

isothermal change $pV =$ constant

heat engines

efficiency $= \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H}$

maximum theoretical efficiency $= \frac{T_H - T_C}{T_H}$

work done per cycle = area of loop

input power = calorific value × fuel flow rate

indicated power = (area of $p - V$ loop) × (number of cycles per second) × (number of cylinders)

output or brake power $P = T\omega$

friction power = indicated power – brake power

heat pumps and refrigerators

refrigerator: $COP_{ref} = \frac{Q_C}{W} = \frac{Q_C}{Q_H - Q_C}$

heat pump: $COP_{hp} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C}$

Turning points in physics

electrons in fields $F = \frac{eV}{d}$

$F = Bev$

$r = \frac{mv}{Be}$

$\frac{1}{2}mv^2 = eV$

Millikan's experiment $\frac{QV}{d} = mg$

$F = 6\pi\eta r v$

Maxwell's formula $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$

$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$

special relativity $t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$

$l = l_0\sqrt{1 - \frac{v^2}{c^2}}$

$E = mc^2 = \frac{m_0c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$

Electronics

resonant frequency $f_0 = \frac{1}{2\pi\sqrt{LC}}$

Q-factor $Q = \frac{f_0}{f_B}$

operational amplifiers: open loop $V_{out} = A_{OL}(V_+ - V_-)$

inverting amplifier $\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$

non-inverting amplifier $\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$

summing amplifier $V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \cdots\right)$

difference amplifier $V_{out} = (V_+ - V_-)\frac{R_f}{R_1}$

Bandwidth requirement:

for AM bandwidth $= 2f_M$

for FM bandwidth $= 2(\Delta f + f_M)$

Acknowledgements

This document has been produced by Mr J Turnbull.

All relevant information has been credited in the document.

This document has been produced for educational purposes only.

This document has been produced for the AQA A Level Physics Specification.

Student Voice

If you when using this document, you believe there is an improvement to made, please state this in the space below….

Only constructive and reasoned feedback will be considered.