Year 13

A Level Physics

Surname:

First Name:

Day 1 – 10 Pack

Easter 2024

Time: **10 hours**

Mark scheme included.

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Nuclear Radius and Types of Radiation (5 hours)

Paper 2

17: Thermal Physics 1 Specific Heat Capacity and Latent Heat
18: Thermal Physics 2 Gas Laws and the MKTM
19: Gravitational Fields Field Strength and Potential
20: Electric Fields Fields Strength and Potential
21: Fields Comparisons Orbits and Comparisons
22: Capacitors Energy Stored and Exponential Decay
23: Magnetic Fields 1 Magnetic Forces and Flux
24: Magnetic Fields 2 Induction and Transformers
25: Radioactivity 1 Nuclear Radius and Types of Radiation
26: Radioactivity 2 Modes and Rate of Decay
27: Nuclear Physics Binding Energy, Fission and Fusion

1. Qualitative study of Rutherford scattering.
2. Appreciation of how knowledge and understanding of the structure of the nucleus has changed over time.
3. Their properties and experimental identification using simple absorption experiments; applications eg to relative hazards of exposure to humans.
4. Applications also include thickness measurements of aluminium foil paper and steel.
5. Inverse-square law for γ radiation: $I = \frac{k}{x^2}$
6. Experimental verification of inverse-square law.
7. Applications eg to safe handling of radioactive sources.
8. Background radiation; examples of its origins and experimental elimination from calculations.
9. Appreciation of balance between risk and benefits in the uses of radiation in medicine.

Required practical 12: Investigation of the inverse-square law for gamma radiation.

Paper 3

28: Electron Discovery Specific Charge and Millikan
29: Wave-Particle Duality Waves, Quantum and Microscopes
30: Special Relativity Michelson-Morley & Relativistic Speed

Monday: Radiation Notes

Complete this table comparing the properties of alpha, beta and gamma radiation.

	Alpha	Beta	Gamma
Structure (or nature)			
Relative mass			
Relative charge			
Deflection by EM field?			
Ionising power			
Penetrating power			
Range in air			
Stopped by:			

Medical tracers

Describe how a gamma emitter is used in medical diagnosis.

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Explain why only gamma radiation is suitable.

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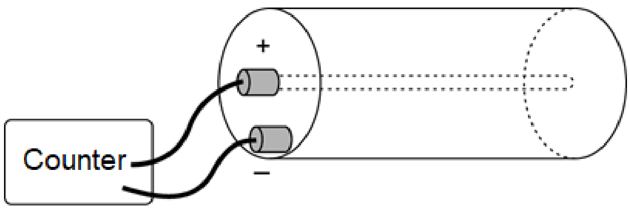
A Geiger-Muller tube connected to a counter can be used to detect the amount of ionising radiation present.

The tube is filled with a non-conducting gas.

Outline what happens when ionising radiation enters the tube and how this leads to a 'count'.



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What is 'background' radiation?

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List the main contributors to background radiation.

1 ……………………………………………………………………………………………………

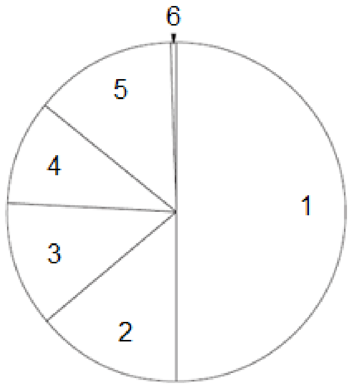
2 ……………………………………………………………………………………………………

3 ……………………………………………………………………………………………………

4 ……………………………………………………………………………………………………

5 ……………………………………………………………………………………………………

6 ……………………………………………………………………………………………………



Describe how the background count rate could be found.

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What does the term 'corrected count rate' mean?

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The inverse square law is given on our equation sheet as:

$$I = \frac{k}{x^2}$$

Symbol I Quantity ……………………………………………………………………………………… Units ………………………

or ………

Symbol x Quantity ……………………………………………………………………………………… Units ………………………

Symbol k Quantity ……

It definitely doesn't represent: ……………………………………………………………………………………………

We often use the inverse square law to predict the count rate at a second point when the count rate at another point is known.

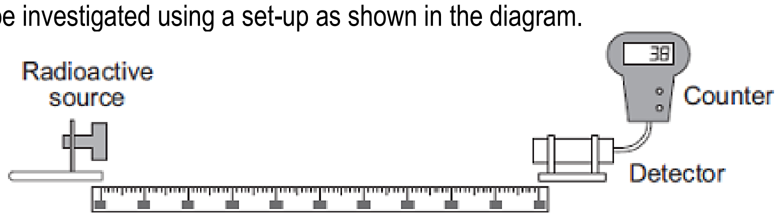
$$I_1(x_1)^2 = I_2(x_2)^2$$

The inverse square law doesn't take into account the background count rate.

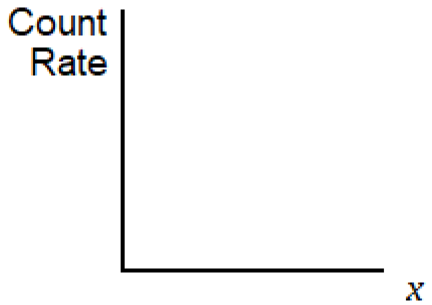
Before using the inverse-square law we need to ……………………………………………………………………………….....

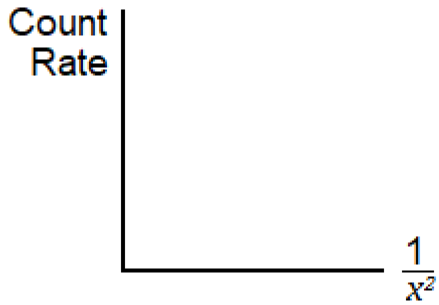
If asked for the reading on the counter we need to ……………………………………………………………………………….....

The inverse square law can be investigated using a set-up as shown in the diagram.



If the results from the investigation followed the inverse square law sketch the graphs that would be obtained.





How else could you tell if the results follow the inverse square law?

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Why might the results not follow the inverse square law?

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Tuesday: Inverse Square Law Exam Questions

Q132(a) Which ionizing radiation produces the greatest number of ion pairs per mm in air? Tick (✓) the correct answer.

α particles	
β particles	
γ rays	
X−rays	

(1)

Q132(bi) Complete the table showing the typical maximum range in air for α and β particles.

Type of radiation	Typical range in air / m
α	
β	

(2)

Q132(bii) γ rays have a range of at least 1 km in air.
However, a γ ray detector placed 0.5 m from a γ ray source detects a noticeably smaller count-rate as it is moved a few centimetres further away from the source.

Explain this observation.

………

………

……… **(1)**

Q132(c) Following an accident, a room is contaminated with dust containing americium which is an α−emitter.
Explain the most hazardous aspect of the presence of this dust to an unprotected human entering the room.

………

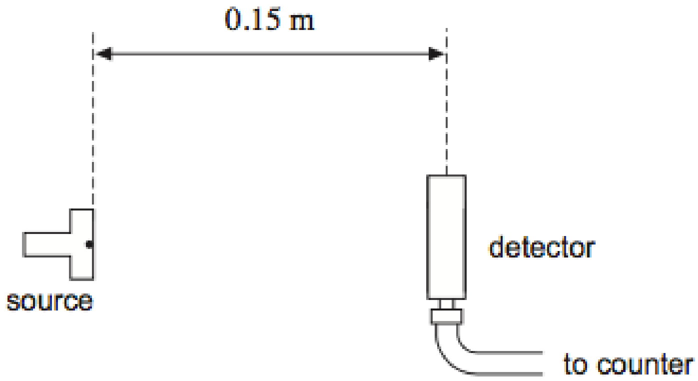
……… **(2)**

Q133(a) The exposure of the general public to background radiation has changed substantially over the past 100 years. State **one** source of radiation that has contributed to this change.

....

.... **(1)**

Q133(b) A student measures background radiation using a detector and determines that background radiation has a mean count-rate of 40 counts per minute. She then places a γ ray source 0.15 m from the detector as shown below.



With this separation the average count per minute was 2050.

The student then moves the detector further from the γ ray source and records the count-rate again.

Q133(bi) Calculate the average count-rate she would expect to record when the source is placed 0.90 m from the detector.

count-rate = ... min^{-1} **(3)**

Q133(bii) The average count per minute of 2050 was determined from a measurement over a period of 5 minutes. Explain why the student might choose to record for longer than 5 minutes when the separation is 0.90 m.

....

....

....

.... **(1)**

Q133(biii) When the detector was moved to 0.90 m the count-rate was lower than that calculated in part **(bi)**. It is suggested that the source may also emit β particles.

Explain how this can be checked.

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....

....

.... **(2)**

(Total 7 marks)

Wednesday: Types of Radiation Extended Writing

A radioactive source used in a school laboratory is thought to emit α and γ. Describe an experiment that may be used to verify the types of radiation emitted by the source. The experiment described should allow you to determine how the intensity of radiation caries with distance in air or with thickness of suitable absorbers. Your answer should include:

- The apparatus you would use
- Any safety precautions you would take
- The measurements you would make
- How the measurements would be used to reach a final decision about the emitted radiation.

Wednesday: Nuclear Radius and Types of Radiation Definitions

	A material suitable for blocking alpha radiation.
	Ionising radiation with a relative mass of 4.
	Alpha particles were fired at this in Rutherford's experiment.
	If the number of nucleons is increased, this will happen to the nuclear radius.
	5 mm of this material will block alpha and beta radiation but not gamma.
	Technetium in an excited state can be described as this.
	If the distance between a Geiger counter and gamma source is halved the activity will be …
	A radiopharmaceutical that is injected or ingested.
	The most ionising radiation.
	A method of measuring the nuclear radius.
	A source of background radiation from the Sun.
	The model of the atom where it has no inner structure.
	Alpha particles gain this type of energy as they approach the gold foil.
	The model of the atom where electrons exist on discrete energy levels.
	Along with concrete this material protects against gamma radiation.
	The model of the atom that first had concentrated mass in the centre.
	Alpha particles lose this type of energy as they approach the gold foil.
	Uncharged ionising radiation.
	The model of the atom that first contained charged particles.
	If the number of nucleons is increased, this will happen to the nuclear density.
	This person's experiment lead to the idea of the nucleus.
	A method of estimating the nuclear radius using alpha particles.
	If the distance between a Geiger counter and gamma source is doubled the activity will be …
	The least ionising radiation.
	The type of radiation what alpha, beta and gamma radiation are.
	The largest contributor to background radiation.
	A source of background radiation due to nuclear weapons testing and use.
	A source of background radiation due to living things.

Alpha	Alpha	Aluminium	Carbon 14
Closest Approach	Cosmic Rays	Electric Potential	Electron Diffraction
Fallout	Gamma	Gamma	Gold Foil
Increase	Ionising	Kinetic	Lead

Metastable	Nothing	Nuclear	Paper
Planetary	Plum Pudding	Quadrupled	Quartered
Radon Gas	Rutherford	Solid Sphere	Tracer

Thursday: Nuclear Radius Notes

Describe the plum pudding model of the atom.

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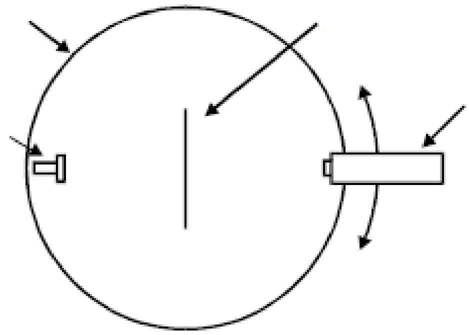
………..

Label this diagram of the experimental set-up.



Why did the results of this experiment lead to the model of the atom being revised?

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Explain what was deduced from the following observations:
A) Most of the alpha particles went straight through without deflection.

………..

………..

B) 1 in 100 were deflected by small angles.

………..

………..

C) 1 in 10000 were deflected by more than 90°.

………..

………..

Why did the air need to be removed from the apparatus?

………..

………..

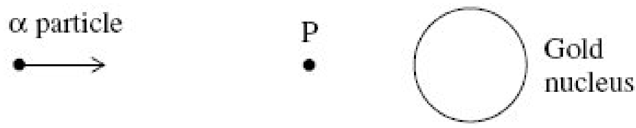
Why does the foil need to be very thin?

………..

………..

………..

The size of the nucleus could be estimated from Rutherford's scattering experiment. The speed of the alpha particles decreases as they approach the gold nucleus due to the electromagnetic repulsion. The alpha particles will eventually come to a complete stop at point P; the kinetic energy has been transformed into electric potential energy.



Derive an equation to calculate the **closest approach** (the closest distance that the alpha particle gets to the nucleus).

Calculate the closest approach if the alpha particles were given an initial kinetic energy of:

2.18 × 10^{-12} J fired at a ${}^{27}_{13}Al$ nucleus.	6.50 × 10^{-13} J fired at a ${}^{31}_{15}P$ nucleus.

The size of a nucleus can be calculated by **electron diffraction**. A beam of high energy electrons is fired at 90° to a thin metal foil and the diffraction pattern is observed similar to that of light through a single slit. A calculation can be made using the first minimum in the electron diffraction pattern.

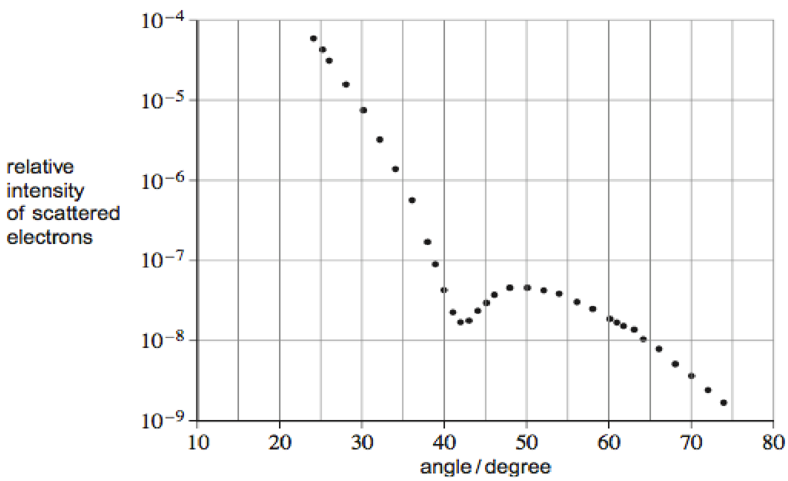
The de Broglie wavelength λ of each electron in the beam is about 3.3 × 10^{-15} m.

The graph shows how the relative intensity of the scattered electrons varies with angle due to diffraction by a nuclei. The angle is measured from the original direction of the beam.

The angle θ of the first minimum in the electron diffraction pattern is given by:

$$\sin\theta = \frac{0.61\lambda}{\text{nuclear radius}}$$

Calculate the radius of this nucleus using information from the graph.



Approximate value of the nuclear radius by: the closest approach of alpha particles: ………………………

the diffraction of electrons: ………………………

The equation for nuclear radius has been derived from experimental data and is given as:

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

Symbol R Quantity ……………………………………………… Units ……………………

Symbol R_0 Quantity ……………………………………………… Units ……………………

Symbol A Quantity ………………………………………………………………………

Derive an equation for the density of a nucleus.

Density	Mass of nucleons and a sphere	Nuclear radius	Cancel out

$$\rho = \frac{m}{V}$$

What is the significance of your final equation? ……………………………………………………………………………………………

……

Friday: Nuclear Radius Exam Questions

Q134(a) Scattering experiments are used to investigate the nuclei of gold atoms.
In one experiment, alpha particles, all of the same energy (monoenergetic), are incident on a foil made from a single isotope of gold.

Q134(ai) State the main interaction when an alpha particle is scattered by a gold nucleus.

……

…… **(1)**

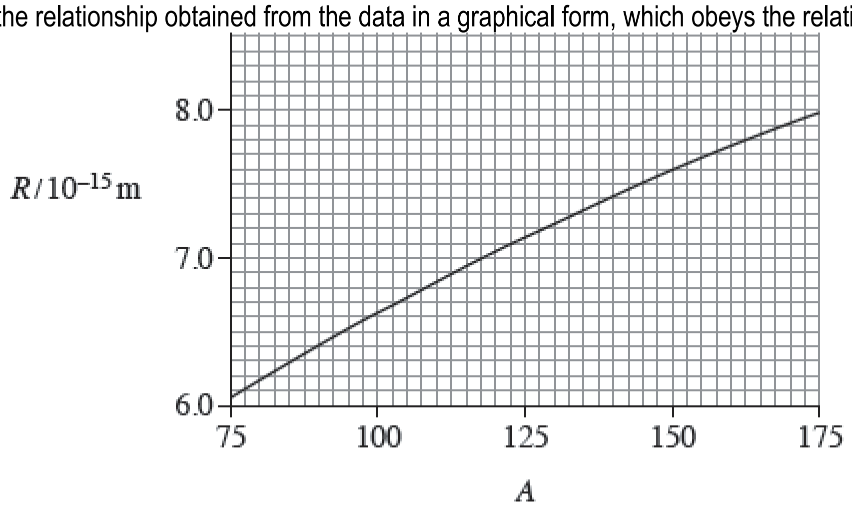
Q134(aii) The gold foil is replaced with another foil of the same size made from a mixture of isotopes of gold. Nothing else in the experiment is changed.
Explain whether or not the scattering distribution of the monoenergetic alpha particles remains the same.

……

……

…… **(1)**

Q134(b) Data from alpha−particle scattering experiments using elements other than gold allow scientists to relate the radius *R*, of a nucleus, to its nucleon number, *A*.
The graph shows the relationship obtained from the data in a graphical form, which obeys the relationship $R = r_0 A^{1/3}$.



Q134(bi) Use information from the graph to show that r_0 is about 1.4×10^{-15} m.

(1)

Q134(bii) Show that the radius of a ${}^{51}_{23}V$ nucleus is about 5 × 10^{-15} m.

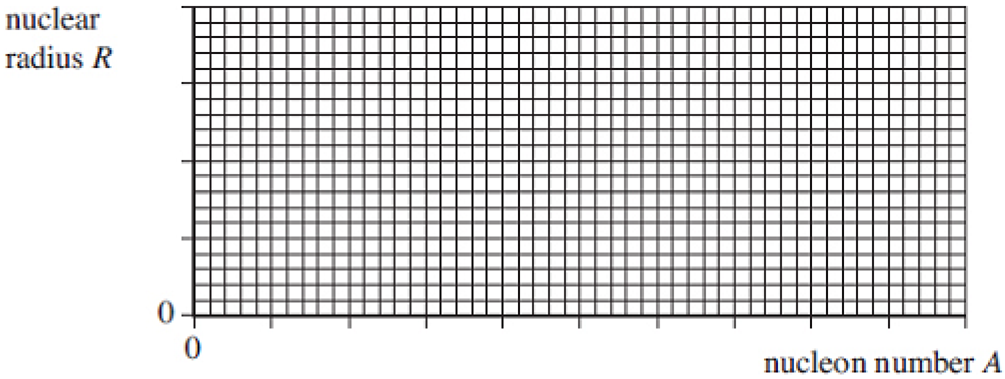
(2)

Q134(c) Calculate the density of a ${}^{51}_{23}V$ nucleus. State an appropriate unit for your answer.

density .... unit .... **(3)**

(Total 8 marks)

Q135(a) On the figure below sketch a graph to show how the radius, *R*, of a nucleus varies with its nucleon number, *A*.



(1)

Q135(bi) The radius of a gold-197 nucleus ${}^{197}_{79}Au$ is 6.87 × 10^{-15} m.
Show that the density of this nucleus is about 2.4 × 10^{17} kg m^{-3}.

(2)

Q135(bii) Using the data from part (bi) calculate the radius of an aluminium-27 nucleus, ${}^{27}_{13}Al$.

answer = ... m **(2)**

Q135(c) Nuclear radii have been investigated using α particles in Rutherford scattering experiments and by using electrons in diffraction experiments. Make comparisons between these two methods of estimating the radius of a nucleus.
Detail of any apparatus used is not required. For each method your answer should contain:

- the principles on which each experiment is based including a reference to an appropriate equation
- an explanation of what may limit the accuracy of each method
- a discussion of the advantages and disadvantages of each method.

....

(6)

(Total 11 marks)

Monday: Radiation Notes

Complete this table comparing the properties of alpha, beta and gamma radiation.

	Alpha	Beta	Gamma
Structure (or nature)	2 protons and 2 neutrons	A high energy electron	A high frequency E.M. wave/photon
Relative mass	4	~1/2000	0
Relative charge	+2	-1	0
Deflection by EM field?	Yes	Yes	No
Ionising power	Highest	←	Lowest
Penetrating power	Lowest	→	Highest
Range in air	~5cm	~1m	~15m
Stopped by:	Paper or metal foil	~3mm Aluminium	~5cm of lead

Medical tracers

Describe how a gamma emitter is used in medical diagnosis.

The patient is given a solution containing a radioactive isotope attached to a molecule used by the specific organ of the human body. It accumulates there, decays and emits radiation which is detected

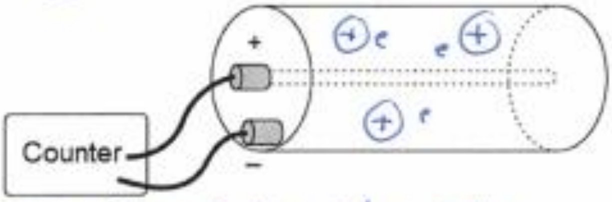
Explain why only gamma radiation is suitable.

Gamma is the most penetrating so can be detected outside of the body. It is also the least ionising

A Geiger-Muller tube connected to a counter can be used to detect the amount of ionising radiation present.

The tube is filled with a non-conducting gas.

Outline what happens when ionising radiation enters the tube and how this leads to a 'count'.



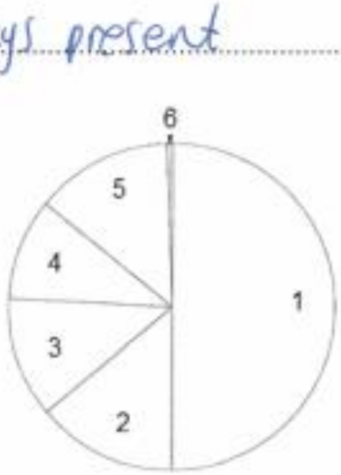
The radiation ionises the gas atoms inside of the tube. The electron is attracted to the rod and the positive ion to the wall (of the tube). The pulse of charge (current) is measured

What is 'background' radiation?

The level of radioactivity (radiation) that is always present

List the main contributors to background radiation.

1. Radon gas (in the air and from rocks)
2. Cosmic rays
3. Food and drink (C-14)
4. Medical (eg. X-rays)
5. Rocks/the ground / buildings
6. Nuclear weapons + air travel + nuclear power



Describe how the background count rate could be found.

Run a Geiger counter away from sources of radiation for 30 minutes. Divide the recorded value by 30 (or 30×60)

What does the term 'corrected count rate' mean?

The count rate with the background count rate taken away.

The inverse square law is given on our equation sheet as:

$$I = \frac{k}{x^2}$$

Symbol I Quantity Intensity of the radiation Units $W\ m^{-2}$

or The count rate

Symbol x Quantity Distance from the source to that point Units m

Symbol k Quantity A constant to be calculated (or is given)

It definitely doesn't represent: the boltzmann constant

We often use the inverse square law to predict the count rate at a second point when the count rate at another point is known.

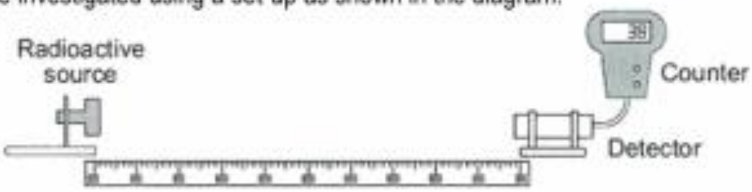
$$I_1(x_1)^2 = I_2(x_2)^2$$

The inverse square law doesn't take into account the background count rate.

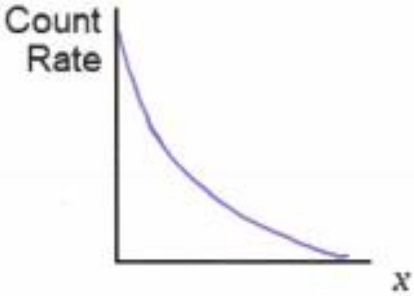
Before using the inverse-square law we need to Subtract the background count

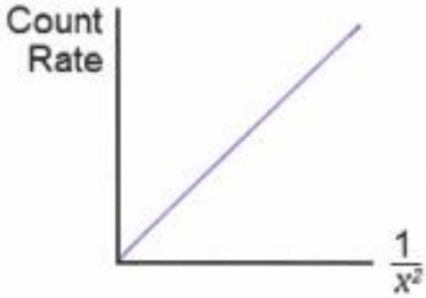
If asked for the reading on the counter we need to Add on the background count

The inverse square law can be investigated using a set-up as shown in the diagram.



If the results from the investigation followed the inverse square law sketch the graphs that would be obtained.





How else could you tell if the results follow the inverse square law?

- Calculate the value of k at various distances
- Double the distance, the count rate should fall to a quarter

Why might the results not follow the inverse square law?

- It might not be giving out just gamma
- The distance is to the front of the detector/tube
- The random nature of radiation

Tuesday: Inverse Square Law Exam Questions

M132.(a) A α particles ✓

1

(b) (i)

type of radiation	Typical range in air / m
α	0.04 ✓
β	0.40 ✓

Allow students to use their own distance units in the table
α allow 0.03 → 0.07 m
β allow 0.20 → 3.0 m.
If a range is given in the table use the larger value.
A specific number is required e.g. not just a few cm.

2

(ii) reference to the inverse square law of (γ radiation)
or reference to lowering of the solid angle (subtended by the detector as it moves away)
or radiation is spread out (over a larger surface area as the detector is moved away) ✓

(owtte)
Ignore any references to other types of radiation.
Any contradiction loses the mark. For example, follows inverse square law so intensity falls exponentially.

1

(c) dust may be ingested / taken into the body / breathed in ✓

First mark for ingestion not just on the body

causing (molecules in human tissue / cells) to be made cancerous / killed / damaged by ionisation ✓

Second mark for idea of damage from ionisation

2

[6]

M133. (a) nuclear fallout / testing / weapons / nuclear accidents / Chernobyl / nuclear waste / nuclear medicine / X-rays / specific uses of radioactive sources eg medical tracers CT scan etc. / cosmic rays as a result of air travel ✓
(Any source of radiation that an individual may encounter which would not have existed 100 years ago)

No mark for general answers such as 'medical' or Nuclear Power / nuclear plant.

If a list is given all must be correct but ignore generalisations such as medical or nuclear power.

1

(b) (i) I_{15CCR} = 2050 – 40 = 2010 ✓

Use of inverse square law eg $I_{CCR90} = I_{CCR15}\left(\frac{d_{15}}{d_{90}}\right)^2$ ✓ = 2010 × (0.15 / 0.90)^2 = 55.8

I_{90CR} = 55.8 + 40

I_{90CR} = 96 counts min^{-1} ✓

regardless of order:

1st mark subtraction of background in original data

2nd mark is for using inverse square function

3rd mark is for the answer

3

(ii) (reduce impact of) random error / decrease the (percentage) uncertainty / improve the statistics (because the percentage error is proportional to the inverse square-root of the count) ✓ (owtte)

The answer must be an uncertainty related statement and not increases reliability / accuracy or increased chance of a reading (although these ideas can accompany a correct answer) Ignore comparisons with the background count.

1

(iii) use (sensible) absorber between source and detector ✓ (sensible absorber means it must have a noticeable effect e.g. 1mm of metal / aluminium sheet / 5mm perspex but do not allow metal foil / paper sheets. Also its effect must not be so great that it reduces the gamma rays noticeably)

(These two marks are independent)
β shown by count rate falling when sheet of aluminium absorber is used ✓ Or (using the existing apparatus)
Compare the results (at various distances) in air with the expected inverse square law ✓
Below the range of beta law does not work but above range it does. ✓

2nd mark no mark given if count rate falls to zero as γ is still present

(magnetic deflection is not common but if seen.

Use of magnetic deflection ✓correct deflection of beta from the beam ✓)

(If a cloud chamber is suggested. Observe the tracks in a cloud chamber ✓beta tracks have varying lengths or they are curly / not straight ✓

(The value of the range of beta is not a marking point so accept 15 – 80 cm if a number is given)

2

[7]

Year 13 Physics: Radioactivity

Extended Writing Task 32: **Types of Radiation**

This work was done by ______________________________ and was marked by ______________________________

S	

D answer			B answer			A* answer		
Some of the equipment needed is listed but generic terms are used e.g. 'detector' or 'absorber'.			Most of the equipment needed is listed and named e.g. GM tube/counter.			All of the equipment needed is named with specific details given e.g. length (5mm of Al).		
The reference to safety precautions is unrealistic for a school setting or is missing.			There is one realistic safety precaution named e.g. use tongs to move the source.			There is more than one realistic safety precautions named.		
There is a broad statement that background radiation should be measured or 'taken into account' (owtte).			There is a basic description of how background radiation could be measured...			...which needs to be removed or subtracted from all other measurements of count rate.		
The method described to taken measurement has the independent variable identified but is weak.			The method described will enable useable results to be collected. The measurements that need to be made are listed...			...including the range/interval of independent variable with at least one control variable listed.		
There is a simple statement that αparticles are stopped by paper or a few cm of air so the count rate will dramatically lower behind the paper...			...beta particles are stopped by a few mm of aluminium (and gamma isn't)...			...so if the count rate through paper and aluminium are similar gamma radiation is emitted but beta particles are not.		
There is a simple statement that α particles have a range of a few cm in air so the count rate will dramatically lower after 5 cm...			...gamma radiation has a greater range in air and will still be detected over a metre away from the source (above background)...			...and should follow an inverse square law (this could be described instead of named).		

		Develop…		**Grade**	**Effort**
T		Range ↓			
		Depth →			
		Order ⋮			
		Relevant !			

E

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Wednesday: Nuclear Radius and Types of Radiation Definitions

Paper	A material suitable for blocking alpha radiation.
Alpha	Ionising radiation with a relative mass of 4.
Gold Foil	Alpha particles were fired at this in Rutherford’s experiment.
Increase	If the number of nucleons is increased, this will happen to the nuclear radius.
Aluminium	5 mm of this material will block alpha and beta radiation but not gamma.
Metastable	Technetium in an excited state can be described as this.
Quadrupled	If the distance between a Geiger counter and gamma source is halved the activity will be …
Tracer	A radiopharmaceutical that is injected or ingested.
Alpha	The most ionising radiation.
Electron Diffraction	A method of measuring the nuclear radius.
Cosmic Rays	A source of background radiation from the Sun.
Solid Sphere	The model of the atom where it has no inner structure.
Electric Potential	Alpha particles gain this type of energy as they approach the gold foil.
Planetary	The model of the atom where electrons exist on discrete energy levels.
Lead	Along with concrete this material protects against gamma radiation.
Nuclear	The model of the atom that first had concentrated mass in the centre.
Kinetic	Alpha particles lose this type of energy as they approach the gold foil.
Gamma	Uncharged ionising radiation.
Plum Pudding	The model of the atom that first contained charged particles.
Nothing	If the number of nucleons is increased, this will happen to the nuclear density.
Rutherford	This person’s experiment lead to the idea of the nucleus.
Closest Approach	A method of estimating the nuclear radius using alpha particles.
Quartered	If the distance between a Geiger counter and gamma source is doubled the activity will be …
Gamma	The least ionising radiation.
Ionising	The type of radiation what alpha, beta and gamma radiation are.
Radon Gas	The largest contributor to background radiation.
Fallout	A source of background radiation due to nuclear weapons testing and use.
Carbon 14	A source of background radiation due to living things.

Alpha	Alpha	Aluminium	Carbon 14
Closest Approach	Cosmic Rays	Electric Potential	Electron Diffraction
Fallout	Gamma	Gamma	Gold Foil
Increase	Ionising	Kinetic	Lead

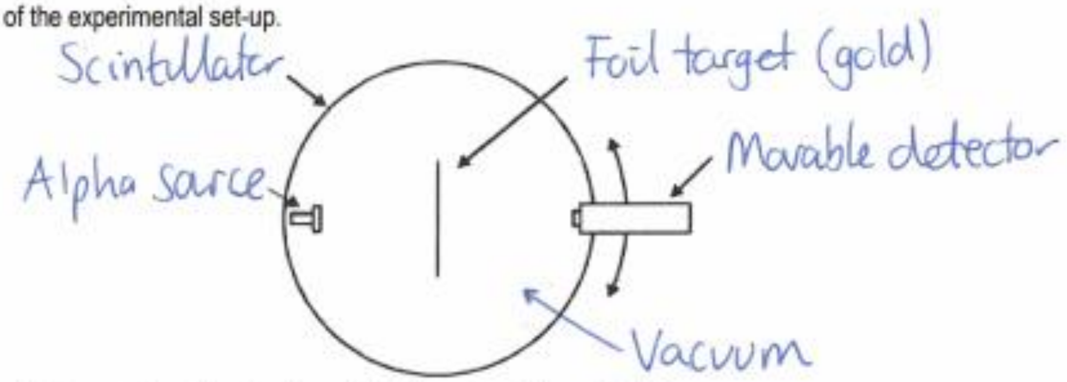
Metastable	Nothing	Nuclear	Paper
Planetary	Plum Pudding	Quadrupled	Quartered
Radon Gas	Rutherford	Solid Sphere	Tracer

Thursday: Nuclear Radius Notes

Describe the plum pudding model of the atom.

A positive 'dough' with negative electrons dispersed randomly through out

Label this diagram of the experimental set-up.



Why did the results of this experiment lead to the model of the atom being revised?

The results couldn't be explained using it; there shouldn't be concentrated mass and/or positive charge capable of repelling the alpha particles

Explain what was deduced from the following observations:

A) Most of the alpha particles went straight through without deflection.

The atom is mostly empty space.

B) 1 in 100 were deflected by small angles.

There is something also positive that can repel the alpha particles

C) 1 in 10000 were deflected by more than 90°.

The positive something also has a high mass compared to the alpha particles.

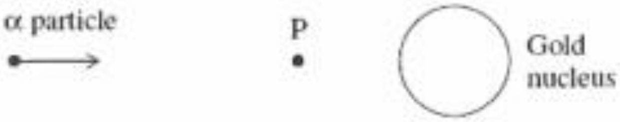
Why did the air need to be removed from the apparatus?

The air would absorb the alpha particles before they reached the foil target (and before they would reach the scintillator).

Why does the foil need to be very thin?

To avoid the alpha particles scattering more than once (by the other layers of atoms - back scattering).

The size of the nucleus could be estimated from Rutherford's scattering experiment. The speed of the alpha particles decreases as they approach the gold nucleus due to the electromagnetic repulsion. The alpha particles will eventually come to a complete stop at point P; the kinetic energy has been transformed into electric potential energy.



Derive an equation to calculate the **closest approach** (the closest distance that the alpha particle gets to the nucleus).

$E_K = E_P \quad E_K = q \cdot \frac{Q}{4\pi\varepsilon_0 d} \quad d = \frac{q \cdot Q}{4\pi\varepsilon_0 E_K}$

Calculate the closest approach if the alpha particles were given an initial kinetic energy of:

2.18 × 10⁻¹² J fired at a $^{27}_{13}Al$ nucleus.

$d = \frac{(2 \times 1.6\times10^{-19})(13\times1.6\times10^{-19})}{4\pi\varepsilon_0 (2.18\times10^{-12})}$

$d = 2.75\times10^{-15}$ m

6.50 × 10⁻¹³ J fired at a $^{31}_{15}P$ nucleus.

$d = \frac{(2\times1.6\times10^{-19})(15\times1.6\times10^{-19})}{4\pi\varepsilon_0 (6.50\times10^{-13})}$

$d = 1.06\times10^{-14}$ m

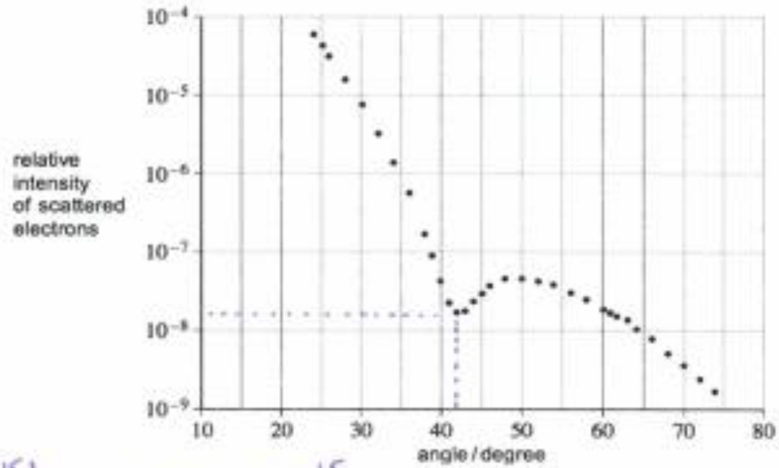
The size of a nucleus can be calculated by **electron diffraction**. A beam of high energy electrons is fired at 90° to a thin metal foil and the diffraction pattern is observed similar to that of light through a single slit. A calculation can be made using the first minimum in the electron diffraction pattern.

The de Broglie wavelength λ of each electron in the beam is about 3.3×10^{-15} m.

The graph shows how the relative intensity of the scattered electrons varies with angle due to diffraction by a nuclei. The angle is measured from the original direction of the beam.

The angle θ of the first minimum in the electron diffraction pattern is given by:

$$\sin\theta = \frac{0.61\lambda}{\text{nuclear radius}}$$



Calculate the radius of this nucleus using information from the graph.

nuclear radius $= \frac{(0.61)(3.3\times10^{-15})}{\sin 42} = 3.01\times10^{-15}$ m

Approximate value of the nuclear radius by: the closest approach of alpha particles: 45 fm

the diffraction of electrons: 5 fm

The equation for nuclear radius has been derived from experimental data and is given as:

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

Symbol R Quantity Nuclear radius Units m

Symbol R_0 Quantity A constant (calculated from measurements) Units m

Symbol A Quantity Nucleon number

Derive an equation for the density of a nucleus.

Density	Mass of nucleons and a sphere	Nuclear radius	Cancel out
$\rho = \frac{m}{V}$	$\rho = \frac{Au}{\frac{4}{3}\pi R^3}$	$\rho = \frac{Au}{\frac{4}{3}\pi (R_0 A^{1/3})^3}$	$\rho = \frac{u}{\frac{4}{3}\pi R_0^3}$

What is the significance of your final equation? It is a constant and so does not depend on the nucleon number / size of the nucleus.

Friday: Nuclear Radius Exam Questions

M134.(a) (i) electromagnetic / electrostatic / Coulomb (repulsion between the alpha particles and the nuclei) ✓

The interaction must be named not just described.

1

(ii) the scattering distribution remains the same (because the alpha particles interact with a nucleus) whose charge / proton number / atomic number remains the same or the (repulsive) force remains the same

The mark requires a described distribution <u>and the reason</u> for it.

Or

the scattering distribution changes / becomes less distinct because there is a mixture of nuclear <u>masses</u> (which gives a mixture of nuclear recoils) ✓ (owtte)

A reference must be made to mass and not density or size.

1

(b) (i) use of graph to find r_0

e.g. $r_0 = 6.0 \times 10^{-15} / 75^{1/3}$ ✓

(or $8.0 \times 10^{-15} / 175^{1/3}$)

($r_0 = 1.43 \times 10^{-15}$ m)

Substitution and calculation t must be shown.

Condone a gradient calculation on <u>R against $A^{1/3}$</u> graph (not graph in question) as $R \propto A^{1/3}$

1

(ii) (using $R = r_0 A^{1/3}$)

$R = 1.43 \times 10^{-15} \times 51^{1/3}$ ✓

$R = 5.3 \times 10^{-15}$ (m) ✓

($R = 5.2 \times 10^{-15}$ m from

$r_0 = 1.4 \times 10^{-15}$ m)

First mark for working.

Second mark for evaluation which must be 2 or more sig figs allow CE from (i) R = 3.71 × (i).

2

(c) density = mass / volume

$m = 51 \times 1.67 \times 10^{-27}$

($= 8.5 \times 10^{-26}$ kg)

Give the first mark for substitution of data into the top line or bottom line of the calculation of density.

$v = 4/3\pi\,(5.3 \times 10^{-15})^3$

($6.2(4) \times 10^{-43}$ m^3)

In the second alternative the mark for the substitution is only given if the working equation is given as well.

Or

density = $A \times$ u / $4/3\pi\,(r_0 A^{1/3})^3$

= u /$4/3\pi\,(r_0)^3$

$51 \times 1.67 \times 10^{-27}$ would gain a mark on its own but 1.66×10^{-27} would need u / $4/3\,\pi(r_0)^3$ as well to gain the mark.

top line = 1.66×10^{-27}

bottom line = $4/3\pi\,(1.43 \times 10^{-15})^3$

✓ for one substitution

density = 1.4×10^{17} ✓

(1.37×10^{17})
kg m^{-3} ✓

Expect a large spread of possible answers. For example
If $R = 5 \times 10^{-15}$ $V = 5.24 \times 10^{-43}$ and density = 1.63×10^{17}.

3

[8]

M135. (a) graph starting (steeply) near/at the origin and decreasing in gradient ✓

1

(b) (i) (use of density = mass/volume)

$$\frac{197 \times 1.67 \times 10^{-27}}{\frac{4}{3}\pi(6.87 \times 10^{-15})^3}$$ ✓ ✓ mark for top line and mark for bottom line

(allow use of 1.66×10^{-27})

Lose mass line mark if reference is made to mass of electrons

$= 2.4(2) \times 10^{17}$ kg m^{-3}

2

(ii) $$R_{Al} = R_{Au}\left(\frac{A_{Al}}{A_{Au}}\right)^{\frac{1}{3}} = 6.87 \times 10^{-15}\left(\frac{27}{197}\right)^{\frac{1}{3}}$$ ✓

$= 3.54 \times 10^{-15}$ m ✓

or

$$r_0 = \frac{R}{A^{\frac{1}{3}}} = \frac{6.87 \times 10^{-15}}{197^{\frac{1}{3}}} = 1.18 \times 10^{-15}$$ m ✓

$$R = 1.18 \times 10^{-15} \times 27^{\frac{1}{3}} = 3.54 \times 10^{-15}$$ m ✓

or

volume = mass/density = $$\frac{27 \times 1.67 \times 10^{-27}}{2.42 \times 10^{17}} = \frac{4}{3}\pi \times R^3$$ ✓

$= 3.54 \times 10^{-15}$ m ✓

2

(c) **principles**

- α scattering involves coulomb or electrostatic repulsion
- electron diffraction treats the electron as a wave having a de Broglie wavelength
- some reference to an equation, for example $\lambda = h/mv$; $eV = mv^2/2$; $Qq/4\pi\varepsilon_o r = E_\alpha$; $\sin\Theta = 0.61\lambda/R$
- reference to first minimum for electron diffraction

accuracy

- α's only measure the least distance of approach, not the radius
- α's have a finite size which must be taken into account
- electrons need to have high speed/kinetic energy
- to have a small wavelength or wavelength comparable to nuclear diameter, the

wavelength determines the resolution

- the wavelength needs to be of the same order as the nuclear diameter for significant diffraction
- requirement to have a small collision region in order to measure the scattering angle accurately
- importance in obtaining monoenergetic beams
- cannot detect alpha particles with exactly 180° scattering
- need for a thin sample to prevent multiple scattering

advantages and disadvantages

- α-particle measurements are disturbed by the nuclear recoil
- Mark for α-particle measurements are disturbed by the SNF when coming close to the nucleus or electrons are not subject to the strong nuclear force.
- A second mark can be given for reference to SNF if they add electrons are leptons or alpha particles are hadrons.
- α's are scattered only by the protons and not all the nucleons that make up the nucleus
- visibility – the first minimum of the electron diffraction is often difficult to determine as it superposes on other scattering events

6

[11]

Turning points Revision – 2 hours

Key knowledge Questions (30 minutes)

Turning Points (Option) part 1 – Discovery of the electron

1. What does thermionic emission mean?

2. What is specific charge?

Calculate the specific charge of:

3. a proton

4. an electron

5. Derive an equation to calculate e/m for an electron travelling at a velocity, v, in a magnetic field of strength B, radius r

6. What does terminal velocity mean?

Turning Points (Option) part 2- Wave-particle duality

1. What was Newton's theory of light?

2. Why was Newton's theory preferred to Huygen's?

3. What is an electromagnetic wave?

4. Why can’t the wave theory of light explain the photoelectric effect?

5. If red light is shone at a metal surface there is no photoelectric emission, explain why.

6. What evidence is there of matter behaving as a wave?

7. State how the de Broglie wavelength of an electron can be increased.

8. What does TEM stand for?

9. How can the resolution be increased?

10. What does STM stand for?

Turning Points (Option) part 3 – Special relativity

1. Why was it so hard to measure the speed of light?

2. Physicists used to believe in absolute motion. What is this?

3. What did the Michelson-Morley experiment prove?

4. What is an inertial frame of reference?

5. What does t_0 stand for in the time dilation equation?

6. What does l_0 stand for in the length contraction equation?

7. 7) If, in the frame of reference of a stationary observer it takes a particle 5 ns to move between two points, will it take a longer or shorter time in the frame of reference of the particle?

8. 8) If, in the frame of reference of a stationary observer a space ship is measured to be 17m long, will it be longer or shorter in the frame of reference of the moving space ship?

9. What happens to the kinetic energy of an object as its speed approaches c?

10) The rest mass of an electron is 9.11 × 10-31 kg at rest. What is its mass when it is travelling at 0.998 c?

Special Relativity Exam Questions (1.5 hours) – Do and then mark

Q1. One of the two postulates of Einstein's theory of special relativity is that the speed of light in free space is invariant.

(a) Explain what is meant by this postulate.

___

___

___

(1)

(b) State the other postulate.

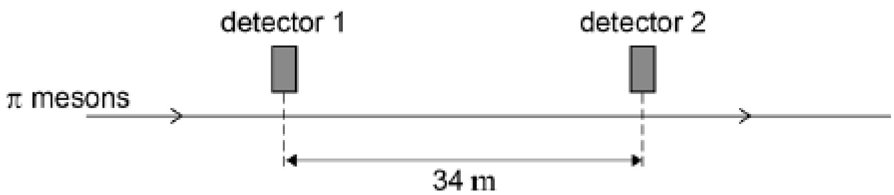
___

___

___

(1)

(c) Two detectors are measured to be 34 m apart by an observer in a stationary frame of reference. A beam of π mesons travel in a straight line at a speed of 0.95 *c* past the two detectors, as shown in the figure below.



Calculate the time taken, in the frame of reference of the observer, for a π meson to travel between the two detectors.

time = ____________________

(1)

(d) π mesons are unstable and decay with a half-life of 18 ns.

It is found in experiments that approximately 75% of the π mesons that pass the first detector decay before reaching the second detector.

Show how this provides evidence to support the theory of special relativity. In your answer compare the percentage expected by the laboratory observer with and without application of the theory of special relativity.

(5)

(Total 8 marks)

Q2.

Cosmic rays detected on a spacecraft are protons with a total energy of 3.7×10^9 eV.

Calculate the velocity of the protons as a fraction of the speed of light.

proton velocity = ____________________ c **(Total 3 marks)**

Q3.

(a) A student models a spacecraft journey that takes one year. The spacecraft travels directly away from an observer at a speed of 1.2×10^7 m s^{-1}. The student predicts that a clock stationary relative to the observer will record a time several days **longer** than an identical clock on the spacecraft.

Comment on the student's prediction. Support your answer with a time dilation calculation.

(4)

(b) In practice, the gravitational field of the Sun affects the motion of the spacecraft and it does not travel directly away from the Earth throughout the journey.

Explain why this means that the theory of special relativity cannot be applied to the journey.

(2)
(Total 6 marks)

Q4.

(a) A muon travels at a speed of 0.95*c* relative to an observer.

The muon travels a distance of 2.5×10^3 m between two points in the frame of reference of the observer.

Calculate the distance between these two points in the frame of reference of the muon.

distance = ________________ m

(2)

(b) Measurements of muons created by cosmic rays can be used to demonstrate relativistic time dilation.

State the measurements made and the observation that provides evidence for relativistic time dilation.

___

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(2)

(c) As the muons travel through the atmosphere, their speeds are reduced by interaction with the particles in the air.

Discuss, with reference to relativity, the effect that this reduction of speed has on the rate of detection of the muons on the surface of the Earth.

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(3)

(Total 7 marks)

Q5.

(a) State what is meant by an inertial frame of reference.

(1)

(b) A pair of detectors is set up to measure the intensity of a parallel beam of unstable particles. In the reference frame of the laboratory, the detectors are separated by a distance of 45 m. The speed of the particles in the beam is 0.97c.

The intensity of the beam at the second detector is 12.5% of the intensity at the first detector.

Calculate the half-life of the particles in the reference frame in which they are at rest.

half-life = ________________ s

(4)

(c) In calculations involving time dilation, it is important to identify proper time.

Identify the proper time in the calculation in part (b).

(1)

(Total 6 marks)

Complete 140 XP of uplearn on these topics. This include strengthening your up score for topics you have already watched.

-Electric Potential and Potential Energy
Gravitational Potential Energy
Gravitational Potential
Comparing Gravitational and Electric Fields
Kinetic Theory of Gases
Discharging a Capacitor

Paper 2 Worst topic exam questions (1 Hour)

Q1.

(a) State the law that governs the magnitude of the force between two point masses.

____

____

____

____

(2)

(b) The table shows how the gravitational potential varies for three points above the centre of the Sun.

distance from centre of Sun/10^8 m	gravitational potential/10^{10} J kg^{-1}
7.0 (surface of Sun)	–19
16	–8.3
35	–3.8

(i) Show that the data suggest that the potential is inversely proportional to the distance from the centre of the Sun.

(2)

(ii) Use the data to determine the gravitational field strength near the surface of the Sun.

(3)

(iii) Calculate the change in gravitational potential energy needed for the Earth to escape from the gravitational attraction of the Sun.

mass of the Earth = 6.0×10^{24} kg
distance of Earth from centre of Sun = 1.5×10^{11} m

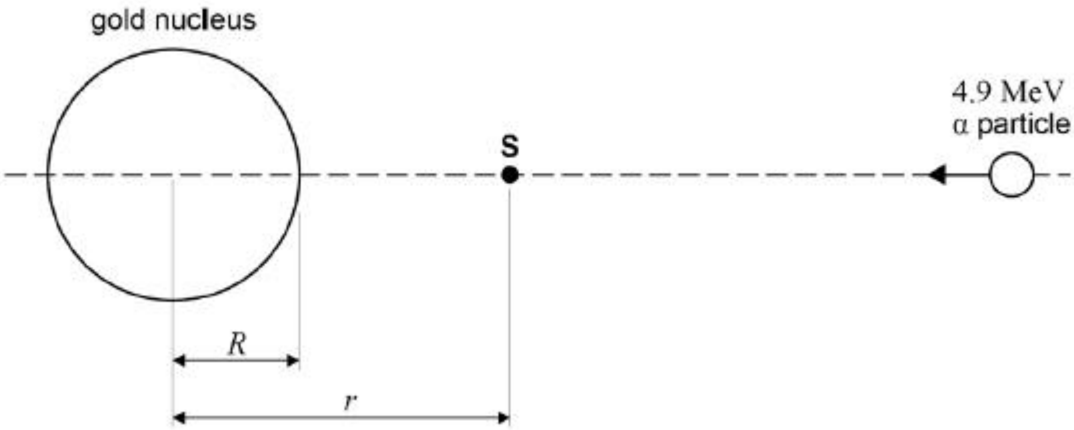
(3)

(iv) Calculate the kinetic energy of the Earth due to its orbital speed around the Sun and hence find the minimum energy that would be needed for the Earth to escape from its orbit. Assume that the Earth moves in a circular orbit.

(3)(Total 13 marks)

Q2.

An α particle with an initial kinetic energy of 4.9 MeV is directed towards the centre of a gold nucleus of radius R which contains 79 protons. The α particle is brought to rest at point **S**, a distance r from the centre of the nucleus as shown in the diagram below.



(a) Calculate the electric potential energy, in J, of the α particle at point **S**.

electric potential energy = ____________________ J

(2)

(b) Calculate r, the distance of closest approach of the α particle to the nucleus.

r = ____________________ m

(3)

(c) Determine the number of nucleons in the gold nucleus.

R, radius of the gold nucleus = 7.16×10^{-15} m
$R_0 = 1.23 \times 10^{-15}$ m

number of nucleons = _________________

(3)

(d) The target nucleus is changed to one that has fewer protons. The α particle is given the same initial kinetic energy.

Explain, without further calculation, any changes that occur to the distance r. Ignore any recoil effects.

(2)
(Total 10 marks)

Q3.

(a) State what is meant by the internal energy of a gas.

(2)

(b) Absolute zero of temperature can be interpreted in terms of the ideal gas laws or the kinetic energy of particles in an ideal gas.

Describe these two interpretations of absolute zero of temperature.

(2)

(c) A mixture of argon atoms and helium atoms is in a cylinder enclosed with a piston. The mixture is at a temperature of 310 K.

Calculate the root mean square speed (c_{rms}) of the argon atoms in the mixture.

molar mass of argon = 4.0×10^{-2} kg mol^{-1}

c_{rms} = ______________________ m s^{-1} **(2)**

(d) Compare the mean kinetic energy of the argon atoms and the helium atoms in the mixture.

(2)

(e) Explain, in terms of the kinetic theory model, why a pressure is exerted by the gas on the piston.

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(3)

(f) The mixture of gases in the cylinder stays the same.

Explain, using the kinetic theory model, **two** changes that can be made independently to reduce the pressure exerted by the gas.

____

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(3)

(Total 14 marks)

Markschemes

Turning points key knowledge

1.What does thermionic emission mean?

The release of electrons from a heated metal surface

2. What is specific charge?

Charge / mass or the ratio of charge to mass

Calculate the specific charge of:

3. a proton

9.6×10^7 Ckg^{-1}

4. an electron

1.8×10^{11} Ckg^{-1}

5. Derive an equation to calculate e/m for an electron travelling at a velocity, v, in a magnetic field of strength B, radius r.

$e/m = (v^3B)/r$

6. What does terminal velocity mean?

Maximum velocity reached (forces are equal and opposite)

Name the forces acting on a charged oil drop in Millikan's experiment when:

7. the drop is in motion

Weight, force due to electric field, drag force

8. the drop is stationary

Electric force, weight

9. For an electron to remain stationary in a vertical electric field, what must the electric field strength be?

Equal to weight

10. If the volume and density of the oil drop is known, how can the radius be calculated?

$r = \rho Vg / 6\pi \eta v$

1.What was Newton's theory of light?

Light is made of a stream of particles (called corpuscles)

2. Why was Newton's theory preferred to Huygens'?

Newton was respected/successful. Huygens couldn't explain polarisation/double refraction...

3. What is an electromagnetic wave?

Transverse waves made up of oscillating magnetic and electric fields that are perpendicular to each other

4. Why can't the wave theory of light explain the photoelectric effect?

All frequencies should eventually cause emission/there is no time delay with emission

5. If red light is shone at a metal surface there is no photoelectric emission. Explain why.

Energy is less than the work function

6. What evidence is there of matter behaving as a wave?

Electron diffraction

7. State how the de Broglie wavelength of an electron can be increased.

Accelerate it through a higher potential/increase its speed

8. What does TEM stand for?

Travelling electron microscope

9. How can the resolution be increased?

Reduce the de Broglie wavelength

10. What does STM stand for?**Scanning tunnelling microscope**

1.Why was it so hard to measure the speed of light?

Light travels very fast

2. Physicists used to believe in absolute motion. What is this?

Everything moved relative to a fixed background

3. What did the Michelson-Morley experiment prove?

There was no ether

4. What is an inertial frame of reference?

Newton's laws apply

5. What does t_0 stand for in the time dilation equation?

Time to the stationary observer

6. What does l_0 stand for in the length contraction equation?

Length to the stationary observer

7. If, in the frame of reference of a stationary observer, it takes a particle 5 ns to move between two points, will it take a longer or shorter time in the frame of reference of the particle?

Shorter

8. If, in the frame of reference of a stationary observer, a space ship is measured to be 17m long, will it be longer or shorter in the frame of reference of the moving space ship?

Longer

9. What happens to the kinetic energy of an object as its speed approaches c?

Approaches infinity

10. The rest mass of an electron is 9.11 × 10-31 kg at rest. What is its mass when it is travelling at 0.998 c?

1.44×10^{29} kg

Special Relativity Mark schemes

Q1.

(a) speed of light in free space independent of motion of source and / or the observer✓ and of motion of observer

1

(b) laws of physics have the same form in all inertial frames
laws of physics unchanged from one inertial frame to another ✓

1

(c) time taken$\left(= \frac{\text{distance}}{\text{speed}} = \frac{34 \text{ m}}{0.95 \times 3.0 \times 10^8 \text{ m s}^{-1}}\right) = 1.2 \times 10^{-7}$ s✓

1

(d) $t = \frac{18 \text{ ns}}{(1 - 0.95^2 c^2 / c^2)^{1/2}}$ ✓

Allow substitution for this mark

1

time taken for π meson to pass from one detector to the other = 58 ns ✓

1

2 half-lives (approximately) in the detectors' frame of reference. ✓

1

two half-lives corresponds to a reduction to 25 % so 75% of the π mesons passing the first detector do not reach the second detector. ✓
OR
Appreciation that in the lab frame of reference the time is about 6 half-lives had passed✓

1

In 6 half-lives 1 / 64 left so about 90% should have decayed✓

Clear conclusion made
Either Using special relativity gives agreement with experiment
or Failure to use relativity gives too many decaying (WTTE)

1

[8]

Q2.

Conversion of 3.7×10^9 eV to 5.9×10^{-10} J ✓

Accept substitution of $3.7 \times 10^9 \times 1.6 \times 10^{-19}$

Correct use of

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

including correct substitution ✓

0.97(c) ✓

[3]

Q3.

(a) (for Proper time, t_0 = 31,536,000 s / 365 days)
Dilated time, t = 31,561,259 s ✓

Time dilation is 25,259 s / 421 minutes / 7.0 hours / 0.29 days ✓

The recorded time will be longer (as predicted) ✓
The recorded time will be less than several days longer (as predicted) ✓

Accept answers in other units (e.g. 365.3 days)
Accept an answer of 31582876 seconds / 365.5 days where a proper time of 365.25 days has been used.

4

(b) Theory of Special Relativity requires no acceleration ✓

(The spacecraft/frame of reference is) accelerating ✓

Alternative answer:

Theory of Special Relativity requires inertial reference frame ✓

(The spacecraft/frame of reference is) not an inertial reference frame ✓

Accept change in direction / speed / velocity as alternatives for accelerating.

2

[6]

Q4.

(a) Lo = 2500 m

Length = $2500 \times (1 - 0.95^2)^{½}$ ✓

length = 781 (780) m ✓

2

(b) Number of muons passing through detector per second measured at top of mountain/in upper atmosphere AND

Allow "intensity of muons"

Number of muons passing through detector per second measured on ground. ✓

Allow number decayed/difference in numbers at upper atmosphere and ground

Measurements show far fewer muons decay than expected in time taken (in observer's frame of reference) for muons to travel from upper atmosphere to ground (as the clock in muons frame of ref runs slower than observer so half-life appears longer). ✓

Allow more muons reach the ground than expected

2

(c) Lower velocity means

Take longer to travel to ground (in either frame of reference) ✓

And time dilation effect less (in Earth frame of reference)/length contraction effect less (in muon frame of reference) (as not so close to c) ✓

More muons decay before reaching ground so rate of detection reduced ✓

If there is no reference to frame of reference or relativistic effects award Max 1.

Answer needs to be consistent with the implicit frame of reference being discussed

3

[7]

Q5.

(a) One which moves at constant velocity

Allow: a reference frame in which Newton's laws / Newton's first law holds.

1

(b) In frame of particle beam

Distance between detectors = $45\sqrt{1-\frac{(0.97c)^2}{c^2}}$ = 10.9 m ✓

Time = 10.9 / 0.97c = 3.8 × 10^{-8} s ✓

Half-life = time/3 ✓ = 1.3 × 10^{-8} s ✓

MP1 is for determination of distance between detectors in ref frame of particles

MP2 is for determining the time between detectors in the ref frame of particles

MP3 is for use of reduction to 12.5% is equivalent to 3 half-lives

MP4 is for correct final answer

Allow alternative route from ref frame of detectors

4

(c) The time taken for particle beam to travel between detectors 'measured' in the reference frame of particle beam✓

Accept: shortest observable time for a particle passing between detectors.

Accept 3.8×10^{-8} s

1

[6]

Paper 2 Worst Topics Mark schemes

Q1.

(a) force is proportional to the product of the two masses

B1

force is inversely proportional to the square of their separation (condone radius between masses)
or
equation M0 : masses defined A1 separation defined A1

B1

2

(b) (i) appreciation that potential x distance from centre of sun = constant
or calculation of Vr for two sets of values (1.33×10^{20})
or uses distance ratio to calculate new V or r

C1

calculation of all three + conclusion
or uses distance ratios twice+ conclusion
conclusion must be more than 'numbers are same'
(condone 'signs' and no use of powers of 10)

A1

2

(ii) $V = GM/r$ and $g = GM/r^2$
or

$g = V/r$ (no mark for E or $g = V/d$ or $E = V/r$)

B1

substitution of one set of data to obtain GM (1.33×10^{20})
or $19 \times 10^{10}/7 \times 10^8$ seen

B1

271 N kg^{-1} (m s^{-2}) (J kg^{-1} m^{-1})

B1

3

(iii) potential energy of the Earth = $(-)GMm/r$
or potential difference formula + $r^2 = \infty$
or potential at position of Earth = -8.87×10^8 J kg^{-1}
(from $Vr = 1.33 \times 10^{20}$)

C1

correct substitution (allow ecf for *GM* from (ii))
or
potential energy = potential x mass of Earth

C1

change in PE = 5.32×10^{33} J (cnao)
Fd approach is PE so 0 marks

A1

3

(iv) speed of Earth round Sun = $2\pi r/T$ or $\sqrt{\frac{GM}{r}}$
or 3.0×10^{4} m s^{-1}

or KE= $\frac{GMm}{2r}$

B1

KE of Earth = ½ 6 × 10^{24} × their v^2 (2.68×10^{33}J)

B1

energy needed = difference between (iii) and orbital KE
(2.64×10^{33} J)

or KE in orbit = half total energy needed to
escape (−1 for AE)

B1

3

[13]

Q2.

(a) 1eV = 1.6×10^{-19} J

kinetic energy = $1.6 \times 10^{-19} \times 4.9 \times 10^{6} = 7.8(4) \times 10^{-13}$ J ✓

ke lost = pe gained = $7.8(4) \times 10^{-13}$ J ✓

2

(b) using $V = Q / 4\pi\varepsilon_0 r$ and $E_p = qV$

$r = qQ/4\pi\varepsilon_0 E_p$✓

$= (2 \times 1.6 \times 10^{-19}) (79 \times 1.6 \times 10^{-19})/4\pi \times 8.85 \times 10^{-12} \times 7.84 \times 10^{-13}$✓

$r = 4.67(4.64) \times 10^{-14}$ m ✓

3

(c) $A = (R/R_0)^3$ ✓

$= (7.16 \times 10^{-15} / 1.23 \times 10^{-15}\ \text{m})^3$ ✓

= 197 placed on the dotted line ✓

3

(d) *r* gets smaller ✓

less force so needs to travel further to lose same initial ke ✓

Fewer protons means that r will be smaller when alpha particle has the same electrostatic potential energy (as initial kinetic energy)

2

[10]

Q3.

(a) It is the sum/total of the (kinetic and potential) energies of the particles/atoms/molecules (that move at random in the gas) ✓$_1$

✓$_1$ Cannot be an average or a rms energy. Nor a vague reference to an energy of or in the gas.

For reference to kinetic energy of the gas or molecules ✓$_2$

✓$_2$ This is independent of the first mark provided energy of the gas is given in some form. So here an average kinetic energy would be acceptable.

2

(b) (Using) the gas laws it is the temperature at which the volume/pressure of a gas extrapolates to zero

OR

(Using $pV = nRT$ or $pV = NRT$) it is the temperature when pV or V or p is zero

OR

Plotting data of volume (or pressure) against temperature the plot extrapolates and crosses the temperature axis at absolute zero OWTTE ✓$_1$

✓$_{1\ first}$ Condone 'becomes/is zero' or phrases like 'said to be zero' or 'thought to be zero'.

✓$_{1\ second}$ Just quoting Charles' law or the Pressure law is not enough.

✓$_{1\ third}$ Allow the information in the form of a sketch.

(whereas) using the kinetic energy it is the temperature at which the (random) motion stops or can be extrapolated to stop or the kinetic energy (of the particles) is zero. ✓$_2$

✓$_2$ The zero must be very explicit e.g. not just very very small. Allow reference to zero point energy/residual kinetic energy at 0 K/uncertainty at 0 K

2

(c) Mass of argon atom = $\frac{\text{molar mass}}{N_A}$

$= \frac{4.0 \times 10^{-2}}{N_A} = \frac{4.0 \times 10^{-2}}{6.02 \times 10^{23}} = 6.6(4) \times 10^{-26}$ (kg) ✓$_1$

✓$_1$ Substitution of the molar mass or the answer gains the mark. Also

the numbers may be seen in the equation of the second mark.

$$c_{rms} = \left(\frac{3kT}{m}\right)^{1/2}$$

$$= \left(\frac{3\times1.38\times10^{-23}\times310}{6.64\times10^{-26}}\right)^{1/2}$$ ✓$_2$ {k can be in form of a symbol}

✓$_2$ Give a mark for this rearrangement and substitution even if the mass is incorrect.

c_{rms} must be the only unknown in the equation, data and constants to be shown.

= 440 (m s^{-1}) ✓$_3$

✓$_3$ Only allow a correct answer so no ecf from the second mark.

A correct answer gains all three marks

Alternative 1

$$\frac{m(c_{rms})^2}{2} \text{ or } (E_k)_{average} = \left(\frac{3kT}{2}\right) = \frac{3RT}{2N_A}$$ ✓$_{1Alt1}$

✓$_{1Alt1}$ The Mark is for introducing R/N_A in the mean energy equation.

$$c_{rms} = \left(\frac{3RT}{mN_A}\right)^{1/2} = \left(\frac{3\times8.31\times310}{4.0\times10^{-2}}\right)^{1/2}$$ ✓$_{2Alt1}$ {R can be in form of a symbol}

✓$_{2Alt1}$ The mark is for the use of the molar mass.

c_{rms} must be the only unknown in the equation, data and constants to be shown.

= 440 (m s^{-1}) ✓$_{3Alt1}$

✓$_{3Alt1}$ Only allow a correct answer so no ecf from the second mark.

A correct answer gains all three marks

{On most occasions answer 5.7×10^{-10} m s^{-1} yields 2 marks as the wrong mass has been used}

Alternative 2

$$(E_k)_{average} = \frac{3kT}{2} = \frac{3\times1.38\times10^{-23}\times310}{2} = 6.42\times10^{-21} \text{ (J)}$$

OR

$(E_k)_{total} = (E_k)_{average} \times N_A = 6.42 \times 10^{-21} \times 6.02 \times 10^{23}$

$(E_k)_{total} = 3.86 \times 10^3$ (J) ✓$_{1Alt2}$

✓$_{1Alt2}$ The mark can be given for evaluating either the average or the total kinetic energy.

$$c_{rms} = \left(\frac{2\times(\text{their energy})}{\text{molar mass}}\right)^{1/2} = \left(\frac{2\times(E_k)_{total}}{\text{molar mass}}\right)^{1/2}$$

✓$_{2Alt2}$ Give a mark for this rearrangement and substitution even if the

energy is incorrect.

c_{rms} must be the only unknown in the equation, data and constants to be shown.

$$\left(\frac{2 \times 3.86 \times 10^3}{4.0 \times 10^{-2}}\right)^{1/2}$$ ✓$_{2Alt2}$

= 439 (m s^{-1}) ✓$_{3Alt2}$

✓$_{3Alt2}$ Only allow a correct answer so no ecf from the second mark.

A correct answer gains all three marks

{On most occasions answer 5.7 × 10^{-10} m s^{-1} yields 2 marks as the wrong mass has been used}

Note the slightly different answers for the third mark which depends on the route taken.

2

(d) (In equilibrium at the same temperature) both gases have the same <u>mean or average</u> kinetic energy ✓

Allow 'they are the same' as a bold statement. However if this is not an opening statement following the question then 'mean or average' must be used.

2

(e) Particles/atoms/molecules collide with the piston/walls and change momentum ✓$_1$

✓$_1$ Ignore any reference to particles colliding with each other.

(The piston provides the) force = <u>rate of change</u> of momentum or <u>impulse</u>(*Ft*) = change in momentum ✓$_2$

(The particles give a force on the piston producing a pressure)

A relevant reference to pressure = force divided by/over area or F/A ✓$_3$

✓$_3$ Relevant = reference to Piston or arising from the particles. (ie where or what)

If no mark is scored give a mark for P = F/A alone

3

(f) **change**

the volume could be increased

explanation

which increases the <u>time between collisions</u> OR <u>results in less frequent collisions</u> (with the piston/wall so reducing the rate of change of momentum)

OR

which increases the area of the piston/wall (and so reduces the pressure)

change

the temperature could be reduced

explanation

which reduces the momentum (change at the wall)

OR

(and) increases the time between collisions or reduces the frequency of collisions (reducing the rate of change of momentum)

✓ ✓ ✓

An explanation in terms of the gas laws is not acceptable.

3 marks

for 2 changes and 2 explanations

2 marks

for 2 changes and 1 explanation

1 mark

for 1 change with corresponding explanation

OR

2 changes with no adequate explanation

If a wrong change is given, eg. reduce the mass, then only one mark is available for one change with corresponding explanation.

3

[14]