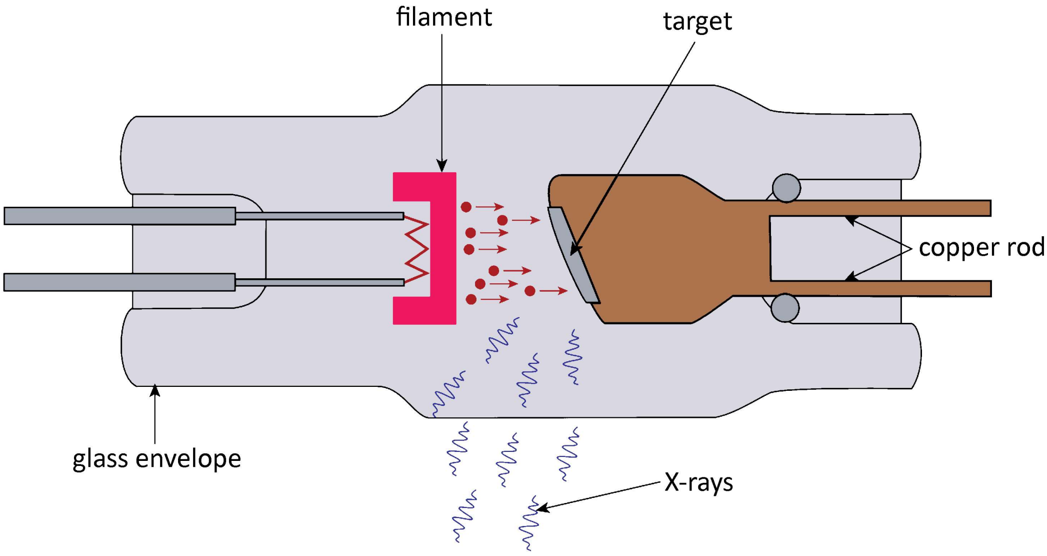
Year 12 Physics NAME________________________

Test: Atoms and Relativity

Total marks: 72

X-rays, Structure of the Atom, Standard Model, Relativity

1. A simple X-ray tube is shown in the diagram below:



(a) State the purpose of the following features of the X-ray tube:

(i) Filament.

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____ (1)

(ii) Copper rod.

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____ (1)

(b) Show that the maximum frequency produced by an X-ray tube is given by $f_{max} = \frac{e\Delta V}{h}$, where ΔV is the potential difference across the X-ray tube.

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____ (3)

(c) Electrons are accelerated through a potential difference of 100 kV in an X-ray tube.

Calculate the minimum wavelength of the X-ray photons produced in this tube.

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(d) Explain the effect that an increase in the potential difference across the X-ray tube has on the penetrating power of the X-rays produced.

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(e) State what is meant by the 'attenuation of X-rays'.

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(f) Explain whether attenuation will be greater in bone or soft tissue.

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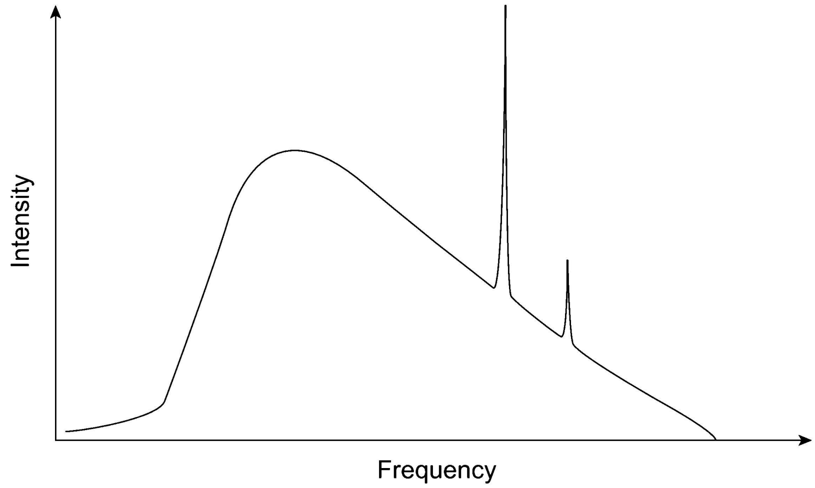
2. An X-ray spectrum produced by an X-ray tube is shown below:



The atomic numbers and melting points of four metals are shown in the table below:

Metal	Atomic number	Melting point (°C)
aluminium	13	659
copper	29	1083
magnesium	12	651
tungsten	74	3399

- Using the information in the table above, identify a suitable metal to be used as the target in an X-ray tube, and explain why the metal that you identified is suitable for the purpose.
- Explain why the spectrum above includes a continuous range of frequencies, and how the characteristic frequencies are produced.

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(a) Explain how the line emission spectrum of a pure element can be used to identify that element in a sample of the material.

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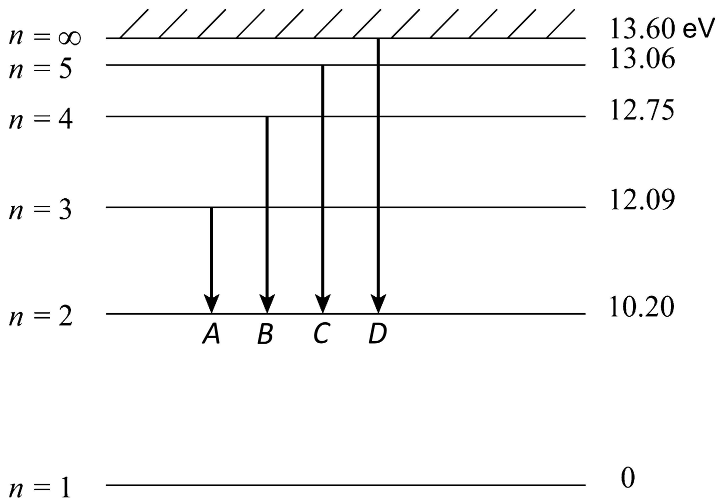
(b) Some of the transitions responsible for an emission spectrum of a hydrogen atom are schematically represented in the energy level diagram below.



(i) Which of the transitions (*A*, *B*, *C* or *D*) in the emission spectrum represented above corresponds to a series limit?

____ (1)

(ii) Calculate the wavelength corresponding to transition *B*.

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____ (3)

(c) Assume that all hydrogen atoms are in the ground state.

(i) *On the energy level diagram* of a hydrogen atom in part (b), draw two of the possible transitions corresponding to the lines in the line absorption spectrum of hydrogen.

(2)

(ii) State, in eV, the ionisation energy of a hydrogen atom in the ground state.

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(iii) Explain why there are no visible absorption lines for hydrogen at room temperature.

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(iv) Absorption lines from hydrogen are observed in the visible part of the Sun's spectrum. Explain the presence of these lines.

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(d) Describe the changes in the observed spectrum of a filament globe as the temperature of the filament increases.

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____ (2)

(e) Describe the process of fluorescence.

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4. A helium-neon laser amplifies light using stimulated emission.

(a) Compare the *process* of stimulated emission with that of spontaneous emission.

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(b) Explain why a metastable state is necessary for a population inversion to occur.

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(c) Explain why a population inversion is necessary to produce a laser beam.

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(d) State two useful properties of the light produced by a laser

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(e) State one requirement for the safe handling of a laser.

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5. The Lambda baryons are a family of hadrons represented by the symbol Λ.

(a) One of the Lambda baryons consists of an up quark, a down quark, and charm quark (*udc*). Calculate the charge on a Lambda baryon with *udc* composition.

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____ (2)

(b) Another Lambda baryon, Λ^0, contains an up quark and a down quark.

(i) State why the Lambda baryon Λ^0 must also contain a third quark.

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____ (1)

(ii) Lambda baryon, Λ^0, contains three different quarks.

Suggest the type of the third quark in Lambda baryon Λ^0.

____ (1)

(c) A Lambda baryon Λ^0 can decay into a proton and a pion.

(i) Show that baryon number is conserved during this reaction.

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(ii) State the charge on the pion.

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(iii) A pion is made of two quarks.

State whether a pion is a lepton, a meson, a baryon, or a gauge boson.

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(d) Decay of a Lambda baryon is mediated by a W boson.

State the name of the fundamental force mediated by W bosons.

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(e) A Lambda baryon can annihilate with an antilambda baryon to produce two gamma photons. Each photon produced this way has an energy of 1.8×10^{-10} J.

Calculate the rest mass of a lambda baryon.

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6. In 2011 scientists working on the Oscillation Project with Emulsion-tRacking Apparatus (OPERA) published results of an experiment showing the speed of muon neutrinos to be 0.002% faster than the speed of light. The controversial results were reported by the media as being one of the biggest scientific discoveries of the century.

OPERA scientists recognised the possibility of an error, but they were unable to find its source. Their results were published online so that other scientists could analyse the data to find the source of the possible error. In 2012 it was discovered that the error was due to a loose cable.

The research director Sergio Bertolucci noted at the time:

> [a]lthough this result isn't as exciting as some would have liked, it is what we all expected deep down. The story captured the public imagination, and has given people the opportunity to see the scientific method in action – an unexpected result was put up for scrutiny, thoroughly investigated and resolved in part thanks to collaboration between normally competing experiments. That's how science moves forward.

Using the information above, explain how science relies on clear communication and on review and verification of results.

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7. Consider the space passenger craft 'Swift Justice' which travelled from Earth to Mercury. To observers on Mercury eagerly awaiting the arrival of their friends and family, the journey was measured to take 873 seconds.

For the passengers aboard Swift Justice, the travel time was only 816 seconds.
Assume the craft travelled with constant velocity and that Earth and Mercury remain stationary relative to each other.

(a) Describe the motion of Mercury relative to a passenger on the Swift Justice.

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(b) Calculate the speed of the Swift Justice relative to the planets. Give your answer as a fraction of the speed of light.

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8. Consider a subatomic particle with a mean lifetime of 2.2 ns and a rest mass of 1.8×10^{-8} kg.

In one laboratory experiment, these particles travelled from one detector to another detector 0.59 m away. The particles travelled this distance in exactly a mean lifetime in the reference frame of the detectors. However, less particles decayed than expected, instead behaving as if the detectors were only 0.26 m apart.

(a) Calculate the Lorentz factor for the particles in this experiment.

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(b) Hence calculate the relativistic momentum of the particles.

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