OCR

G485 possible essay/long answer questions-summary

A2 Physics

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I have highlighted the titles of topics that I think have a higher chance of coming up. However these are just predictions, you never quite know with OCR ;)

Possible G485 essay/long answer questions summarised

- Mass spectrometer

-Used to identify particles once they have been ionised. Movement in electric and magnetic fields can be controlled in such a way that the mass can be measured.
-Firstly the sample is vaporised and ionised
-A fine beam of positively charged ions are then sent into a velocity selector. This has a magnetic flux density and only particles that have a certain velocity will be able to get through a small slit.
-The beam enters a second magnetic field and is deflected. The radius of deflection can be used to measure the mass by using the equation:

$$Bqv = \frac{mv^2}{r}$$

This rearranges to:

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

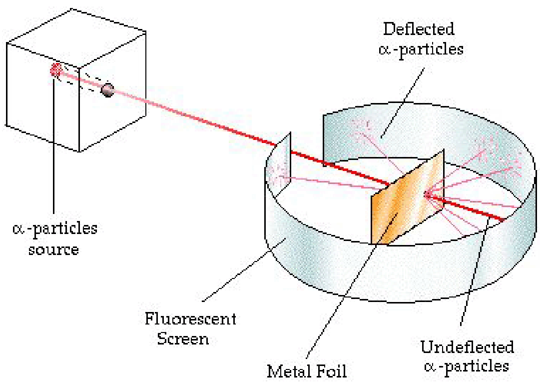
The horizontal velocity stays the same, and so the mass can be worked out with this equation

- Uses of capacitors

-**Flash photography**: when a picture is taken, charge stored in a capacitor flows through a tube of xenon gas which emits a bright light. In order to give a brief flash of light the capacitor has to discharge very quickly to give a high current.
-**Back-up power supply on a computer**: computers are connected to a back-up power supply to ensure that there is no data loss if there is a power cut. These consist of large capacitors that store charge while it is on and discharge very slowly if it goes off.
- **Nuclear fusion:** Z machine in New Mexico has a very large number of high-voltage capacitors that are charged slowly and discharged in a few billionths of a second, generating around 300 terawatts of power.

- Alpha-particle scattering experiment

-Alpha particles are fired at a thin gold target. A zinc sulfide screen that produces a flash of light when an alpha particle hits it is used.
-The kinetic energy was so large that it knocked the gold atoms out of the way the majority of the time and so were not deflected.
-Around 1 in 10000 alpha particles were deflected by more than 90 degrees, which could not be explained at the time the experiment was carried out.
-To get a large enough repulsion on a positive charge the alpha particle needs to get close to the nucleus.
-The only way for the alpha particle to get this close is for the alpha particle to be very small and for the positive charge in the gold atom to be concentrated in a point around 10^{-14}m
-Therefore this experiment led to the model of the atom with the nucleus



- Uses of radioactive isotopes (other than medical)

-**Archaeological dating (carbon dating)**: While alive a tree takes in carbon dioxide to make cellulose. A small fraction of carbon in atmospheric CO_2 is carbon-14, which is radioactive. When the tree dies no more carbon-14 is absorbed and so it begins to undergo radioactive decay, with a half life of around 5570 years. The ratio of carbon-14 to carbon-12 decreases over time, and so can be used to date the sample. An accelerator mass spectrometer can be used to accurately determine the ratio.

-**Smoke detector:** At the top of a smoke detector is an ionisation chamber. In this ionisation chamber is 0.2µg of americium-241, an alpha emitter with a half-life of 432 years.

-This alpha source causes ionisation of the air particles and so an ionisation current runs through the chamber. When smoke particles enter the chamber they become charged by the ions present, reducing the ionisation current. Electronic circuitry detects the reduction in current and sounds the alarm.

- Induced fission

-Fission of a uranium-235 nucleus can be achieved by a slow moving (thermal) neutron being absorbed by the nucleus. This makes the nucleus unstable and particles fly off in all directions.

-Energy from this is 40 million times larger than burning an atom of carbon, and no CO_2 is produced.

-Neutrons are emitted from this reaction and have the same momentum as the larger particles, but because they have a fraction of the mass they will have a high velocity. If they collide with more uranium-235 nuclei a chain reaction can be produced

- Nuclear reactor layout and function

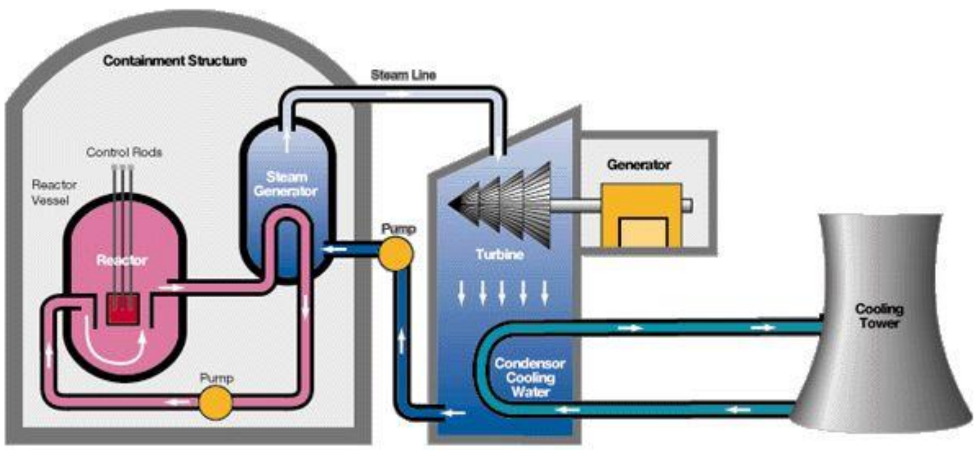
-Key components: Fuel element, moderator, control rods, coolant

-**Coolant**: CO_2 circulates through the reactor and heats up, it then passes through the heat exchanger, in which it loses heat and creates high pressure steam which turns a turbine and generates electricity like a conventional power station.

-**Fuel rods**: consist of the uranium which can undergo fission, creating the neutrons so that a controlled chain reaction can take place. These fuel rods are in special cases made especially to allow the CO_2 coolant to swirl through the spaces between the fuel rod and moderator.

-**Moderator (normally made of carbon)**: these carbon moderators surround the fuel rods and slow the neutrons down so that they become thermal neutrons. These neutrons then drift into the fuel elements and induce nuclear fission.

-**Control rods**: boron rods which can be raised or lowered. Boron can absorb neutrons without undergoing fission, and so these can stop a chain reaction from getting out of control. These control the output of the reactor and will automatically drop down if anything begins to go wrong.



Environmental effects of nuclear power generation (advantages and disadvantages)

☺	☹
Does not produce CO_2 emissions as a by-product of the process	All electrical power has to be generated at the same instant it is used
Can produce energy at all times compared to other sources of energy like wind, which is only produced when plenty of wind is available	Produces radioactive waste which undergoes radioactive decay. Most of it quickly but some has a long half-life and needs to be contained for a long time to avoid damage to plants and animals
Power stations produce warm water which can be used for central heating	Only buildings situated near the power station could take advantage of the central heating

- Production of X-rays

-An external power supply produces up to 200kV between the anode and cathode. This accelerates a beam of electrons across the gap from the cathode to the anode. The kinetic energy of electrons arriving at the anode will be equal to the accelerating voltage, so 200keV in this case.
-When electrons strike the anode at high speed, some of their energy is converted into the form of X-rays, which as scattered in all directions.
-Part of the outer casing (the window) is thinner than the rest, and allows X-rays to emerge in the space outside of the tube.
-The width of the beam can be controlled by metal tubes past the window which can absorb some of the X-rays, producing a parallel-sided beam called a collimated beam.
-Only about 1% of the energy from the electrons is converted into X-rays, the rest is converted into heat at the anode; therefore the tungsten anode is rotated at around 3000rpm to avoid overheating.

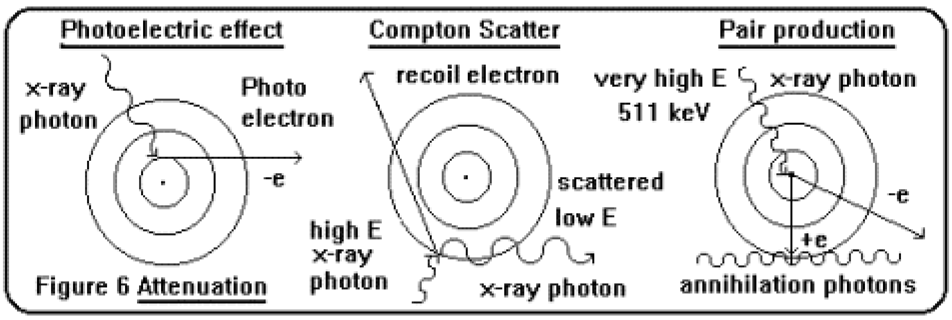
- Absorption of X-rays

-**Photoelectric effect**: low energy X-rays (<100keV) is absorbed by one of the electrons in an atom, and so this electron gains enough energy to escape from the atom. The gap in the electron shell is replaced by another electron, in doing so a photon is emitted (This is related to the work function equation):

$$hf = \emptyset + K_E max$$

-**Compton scattering**: X-ray photon (0.5-5.0 MeV) knocks an electron out of an atom. Interaction between the photon and electron is inelastic, therefore the scattered X-ray photon has less energy than before and so has a greater wavelength. The Compton electron goes off in a different direction to the X-ray photon due to conservation of momentum.

-Pair production: X-ray photon (>1.2MeV) passes through the electric field of the nucleus and produces and electron-positron pair. The positron is soon annihilated by another electron. This method of absorption is not useful in diagnostic X-rays as the energy is too low.



- Image enhancement (X-rays)

-Use **of photographic film that is more sensitive to X-rays** or put a fluorescent **plate behind an X-ray film**, decreasing the exposure.
-**X-ray absorbing substance such as contrast medium**: these have atomic numbers and can increase the contrast of an image. A barium meal is an example of contrast medium, where the patient swallows the barium so that the intestines can be X-rayed, as soft tissue of similar attenuation coefficients will be able to be distinguished between.
-**Image intensifier (digital method)**: a screen is placed under the patient; each tiny dot on the screen is a phosphor that glows under X-rays. This can be recorded with high-quality digital cameras and used to give a moving picture of an organ.

- CAT scan

-Source is shielded so that rays emerge from a point and spread through the patient.
-X-ray beam is fan shaped and has very little thickness, so X-rays only irradiate a thin slice of the patient at a time.
-After passing through the patient, the X-rays are detected by a ring of up to a thousand detectors. The X-ray source is rotated around the patient and moves up the body, taking slice after slice.
-The computer puts the slices together to form a 3D image of an organ on a computer screen which can be rotated.

- Advantages of CAT scanning:

-Can be taken quickly so many patients can be scanned per day, compared to MRI which can take up to ¾ hour per patient.
-The cost of the machines is less than MRI.
-Images show 3D relationships between tissues.
-Can distinguish between tissues of similar attenuation coefficients.

- Medical tracers:

-Can be used for diagnosis of treatment. A number of factors have to be considered first:
-Sources must be gamma emitters as alpha and beta would be absorbed (and could damage) the body.
-Half-life of the source must be long enough to carry out the investigation, but no longer
-Gamma-rays cause some ionisation, so patient will be exposed to some harmful radioactivity, as will patients and staff.
-Source must not be toxic.
-Must be possible to get source to the part of the body where it is needed.
-Once the source is in the body it must be possible to monitor it.

- The gamma camera

1. Gamma photons pass upwards through a collimator, which consists of a honeycomb of cylindrical tubes in a lead plate. The scintillator detects any photons travelling along the axis of these tubes. The collimator therefore cuts out any gamma rays travelling at an angle to the scintillator.
2. The beam of gamma photons then strikes the scintillator crystal, and each photon produces a flash of light.
3. A single light photon releases a single electron from the photocathode by the process of the photoelectric effect. This electron is accelerated by an electrode and on impact releases two or three secondary electrons. This process is repeated at each electrode and soon there is an avalanche of electrons, which eventually give rise to an electrical pulse at the final electrode.
4. The electrical signals from the photomultipliers are processes electronically by a computer to produce an image on a screen, the output from each photomultiplier corresponds to a single pixel on the screen.

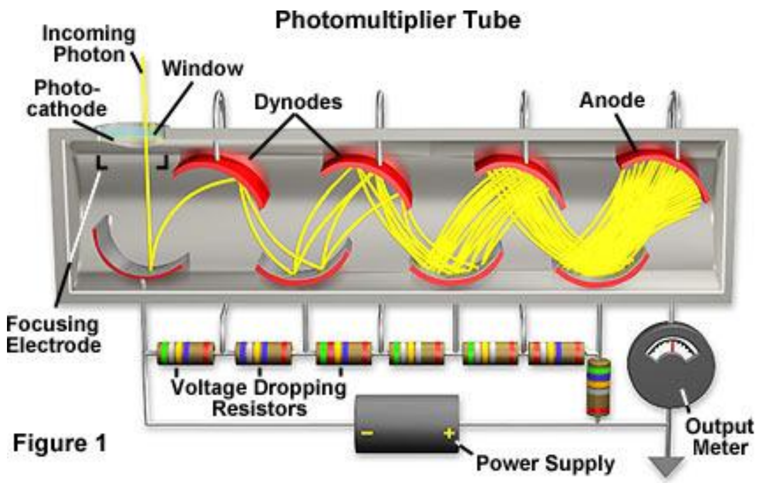


Figure 1

- <u>PET scanning</u>

-Radiopharmaceuticals used are beta plus emitters- an example is fluorine-18.
-Beta plus decay produces a positron, and this positron is soon annihilated by an electron to form two gamma photons, which are emitted 180 degrees to each other.
-The patient is surrounded by a ring of gamma detectors (similar to the gamma camera) which detect the pairs of photons.
-Times at which photons strike the detectors are compared and gradually a 3D image is built up.
-The distribution of radioactivity matches metabolic activity, this is because the radioactive material is taken up by the cells which are doing more work (increased metabolism) giving an indication that something is wrong with that area.

- <u>MRI outline</u>

-Atoms with unequal numbers of protons and neutrons possess a property called spin and are able to act like tiny magnets
- When the patient is placed in a strong magnetic field these atoms align
-A radiofrequency pulse is emitted, which matches the precession frequency of the atoms (Larmor frequency of protons), which causes the atoms to become excited and flip into a higher energy state.
-When the radiofrequency is turned off, the atoms relax back into an unexcited state, in doing so they emit radiofrequency radiation which can be detected
-The relaxation times tell you what environment the atoms are in, and can be used to generate a picture with a computer.
- A gradiated magnetic field is used to locate nuclei in the body.

- Structure of an MRI machine

-Large super conducting magnet which produces magnetic flux density of 2T needed to align protons
-RF coil that transmits RF pulses into the body
-RF coil that detects signal received from relaxing protons
-Set of gradient coils to produce an additional magnetic field across the patient's body which vary the magnetic flux density across the length, width and depth of the patient, ensuring that the Larmor frequency is slightly different for each part of the body, meaning only a small volume of the body will be at a resonant frequency, which the computer can locate and construct a specific image.

- Advantages and disadvantages of MRI

Advantages	**Disadvantages**
☺ No ionising radiation, so no hazard to patients or staff	☹Any metallic objects such as surgical pins can become heated. Heart pacemakers can also be affected, so patients with these cannot be scanned
☺ No moving mechanisms, just changing currents and magnetic fields	☹ Machines are very expensive
☺Gives a better soft tissue contrast than a CAT scan, which does not show bone as clearly either	☹Each scan takes a long time so not many scans can be done per day
☺ Patient feels nothing during the scan and there are no after effects	☹ Equipment cannot have radio waves from external sources in it
☺ Computer images can be generated which are 3D	

- Differences between an A-scan and B-scan (ultrasound)

-A-scan: gives output on a cathode ray tube and does not produce an image. Instead measurements can be taken from the data to determine dimensions.
-B-scan: array of transducers is used together with a fanning out of the ultrasonic beam across the body. Multiple echoes are received and the information is used to build up a picture.

- How a star is born

-Stars are born from a cloud of dust and gas which was left when a previous star blew itself apart in a supernova.
-Denser parts of the cloud clump together under the force of gravity.
-When the clouds get dense enough they fragment into regions called protostars, and continue to contract and heat up.
-Eventually the temperature reaches a few million degrees and it becomes hot enough for hydrogen to fuse into helium.
-This fusion releases enormous amounts of energy, leading to radiation pressure which prevents the star from collapsing under the force of gravity. **This is a main sequence star**.

- Formation of a red giant

-When hydrogen in the core runs out (core hydrogen burning stops), nuclear fusion stops, and so the radiation pressure stops. The core begins to contract and heat up under the weight of the star.
-Material surrounding the core still has hydrogen and so the heating of the core causes hydrogen to fuse into helium in the shell (shell hydrogen burning).
-The core continues to contract and heat up until it gets hot and dense enough for helium to fuse into heavier elements like oxygen and carbon (core helium burning)
-This releases large amounts of energy, causing out layers of the star to be pushed outwards, and these outer layers cool and the star becomes a **red giant**.

-When helium runs out in the core the star contracts again so that helium in the shell begins to be fused (shell helium burning)

- Evolution of a star after a red giant (mass dependant)

-Formation of a white dwarf:
1. In low mass stars the carbon-oxygen core is not hot enough for further fusion, and so the star begins to contract again. When the star has shrunk to around Earth size, electron degeneracy pressure prevents any further contraction.
2. The helium shell becomes more and more unstable as the core contracts, causing the star to pulsate and emit its contents into space via a planetary nebula, leaving the dense hot core behind
3. This is the **white dwarf**, and this will cool down and fade away

-High mass stars (around 8 times the mass of the sun)
1. High mass stars have more fuel but use it up more quickly, and so do not spend as long as main sequence stars.
2. As red giants the core burning to shell burning process continues beyond helium and can go all the way up to heavier elements such as Iron in layers, becoming a **super red giant.**
3. Fusion can go all the way up to iron, beyond this is energetically unfavourable and so the star explodes in a supernova, becoming a neutron star or a black hole.

- Formation of a neutron star (in detail)

-When the core runs out of fuel it starts to contract, forming a white dwarf core.
-If the star is massive enough and the core is about 1.4 times the mass of the sun, electron degeneracy pressure cannot stop the core from contracting.
-Electrons get squashed into nuclei of atoms and combine with protons to form neutrons and neutrinos.
-The core collapses to form a neutron star, which the outer layers fall onto
-Once the outer layers hit the surface they rebound, setting up shockwaves which rip the star apart, causing a supernova.

-If the core is 3 times the mass of the sun, it cannot withstand the gravitational forces and collapses to form a black hole

- Significance of 3K microwave background radiation

-Supports big bang theory as astrophysicists calculated that from the big bang the universe would expand and cool and that background radiation would exist at a few degrees Kelvin. It also highlights that the universe is expanding as they were originally gamma rays that have become redshifted.

- Assumptions of $1/H_0$

-The galaxy in question has been travelling at the same speed throughout its existence. It must have gained gravitational potential energy and so will have lost some kinetic energy and will be travelling below its average speed. Therefore the time since the big bang will actually be lower.
-Uncertainty in the Hubble constant makes age of the universe uncertain
-Not all galaxies were formed at the time of the big bang, this fact has been ignored.

- Evolution of the universe

-T=0s: all the matter in the universe concentrated at one infinitely dense, infinitely hot point known as a singularity
-T=10^{-43}s: all four fundamental forces are unified, rapid expansion takes place
-T=10^{-34}s: gravitational force separates from the other forces, primordial quark soup formed with photons
-T=10^{-16}s: strong nuclear force separates, leptons form from photons.
-T=10^{-3}s: weak nuclear and electromagnetic separate, quarks can exist in protons and neutrons. Ratio of protons to neutrons is 4:1
-T=100s: Helium and lithium nuclei formed, but temperature is becoming too cool for further fusion to occur, matter is currently in a plasma phase where protons are not attached to electrons as temperature is too high.
-T=100 000 years: universe is cool enough for atoms to be formed and becomes transparent as photons are free to travel. CMB is formed.
-T= 1 million years: overall structure of the universe formed.
-T= 1 billion years: universe gains more structure, heavy elements formed from gravitational collapse
-T=13 billion years: present day, ratio of protons: neutrons is still 4:1.

- Density and shape of the universe

-Using the cosmological principle that the universe is homogeneous (same everywhere) we consider that the current mass of the universe divided by the volume gives a mean density of ~10^{-27}kgm^{-3}, which is the **critical density.**

 - Closed universe: current actual density of the universe is greater than the critical density, so the gravitational forces prevent the expansion and ultimately reverse it, leading to the big crunch.
 - Open universe: current actual density of the universe is less than the critical density, so gravitational forces cannot halt the expansion of matter, and the universe will expand forever.
 - Flat universe: current actual density of the universe is equal to the critical density, so the galaxies will gradually slow down over a long time, but never quite stop.

Current belief is that the critical density is equal to the actual density, so the universe is flat.