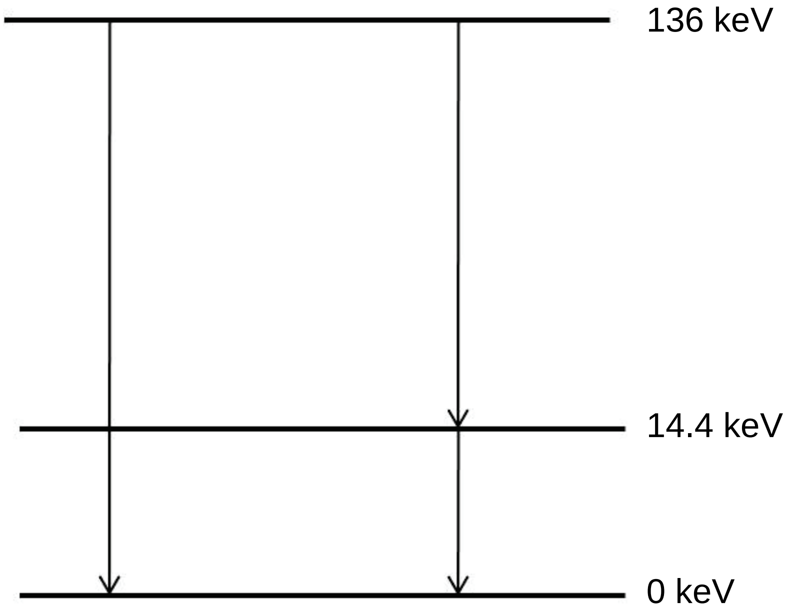
Question 4 **(2 marks)**

An air compressor is located at the open end of a closed pipe. A maintenance worker walked away from the closed end of the pipe and noticed that the sound from the air compressor was getting louder and quieter as he moved toward the open end of the pipe. The worker found that the sound became louder every 1.50 metres. Calculate the frequency of the sound heard, given that the air was at 25°C.

Question 6 **(4 marks)**

When a radioactive isotope undergoes gamma decay, a nucleus in an excited state decays to a lower energy state of the same isotope by the emission of a photon. This decay is similar to the emission of light when an electron in an atom moves from a higher energy level to a lower one. The isotope $^{57}_{26}Fe$ can decay to the ground state in the two ways shown on the energy level diagram below.

Calculate the wavelength of the photon emitted in the transition from the level with energy of 136 keV to the level with energy of 14.4 keV.



Question 9 **(4 marks)**

Describe briefly how Edwin Hubble's observations of the redshifts of galaxies were used to formulate Hubble's Law and explain how Hubble's Law is used to support the Big Bang theory.

Question 13 **(5 marks)**

Earthquakes cause seismic waves to travel through the Earth. These waves are detected by seismometers around the Earth. Two types of seismic waves are P and S waves. P waves are longitudinal and travel at a speed of 5.57 km s^{-1}. S waves are transverse and travel at a speed of 3.56 km s^{-1}.

Give **one** example of a transverse wave and **one** example of a longitudinal wave that you have studied (**not** P and S waves).

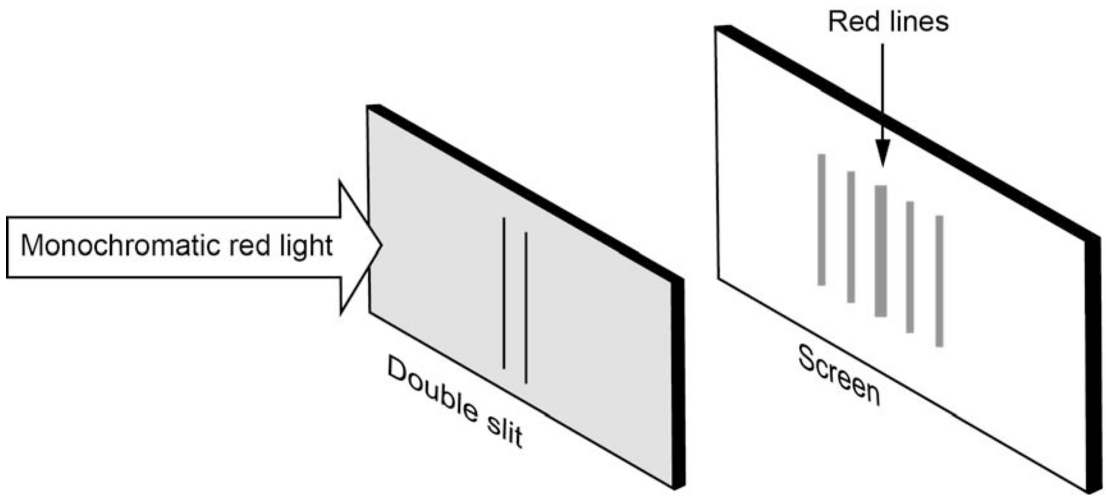
Transverse: ______________________________

Longitudinal: ______________________________

A seismometer records an earthquake. The P waves arrive 13.5 s before the S waves. Calculate the distance between the seismometer and the point of origin of the earthquake waves.

Question 14 **(3 marks)**

The pattern observed when monochromatic light passes through a piece of cardboard with twin slits close together is often considered evidence for the wave theory of light. A diagram of an experiment set up in a classroom is provided below.



Explain how the pattern of red lines is formed on the screen and why this is considered to be evidence for the wave theory of light.

End of Section One

Question 22 **(19 marks)**

Muons and Relativity

Muons are subatomic particles that were discovered in 1936 by researchers studying cosmic radiation. The researchers noticed some particles whose paths in a magnetic field curved in a direction indicating negative charge, with path curvature indicating a mass between a proton mass and an electron mass.

Researchers first thought these particles were hadrons (heavy particles made of quarks). Hadrons such as protons and neutrons consist of three quarks and are called baryons. The new particles were thought to be mesons, that is, hadrons containing two quarks. Hadrons may emit either a neutrino or an antineutrino when they decay.

Further investigation showed that muons emit both a neutrino and an antineutrino when they decay, indicating that muons are leptons – fundamental particles that are not made of quarks. The most familiar lepton is the electron. Muon decay can be summarised as

$$\text{muon} \rightarrow \text{electron} + \text{neutrino} + \text{antineutrino}$$

Most naturally-occurring muons are created when cosmic rays collide with atoms in the upper atmosphere, approximately 10 km above the Earth. A muon has a rest mass of $\frac{106\ \text{MeV}}{c^2}$, a charge of -1 and an average lifetime of 2.2×10^{-6} s.

(a) The table below contains information about some subatomic particles. Complete the last column of the table by writing baryon, meson or lepton to indicate the group of particles to which the individual particle belongs. (4 marks)

Particle	Quark structure	Decay products	Baryon, meson or lepton
Lambda	charm, up, down	proton, pion, kaon	
Tau		tau neutrino, electron, electron anti-neutrino	
Kaon+	strange, charm	muon and muon neutrino	
Xi	up, strange, strange	lambda and pion	

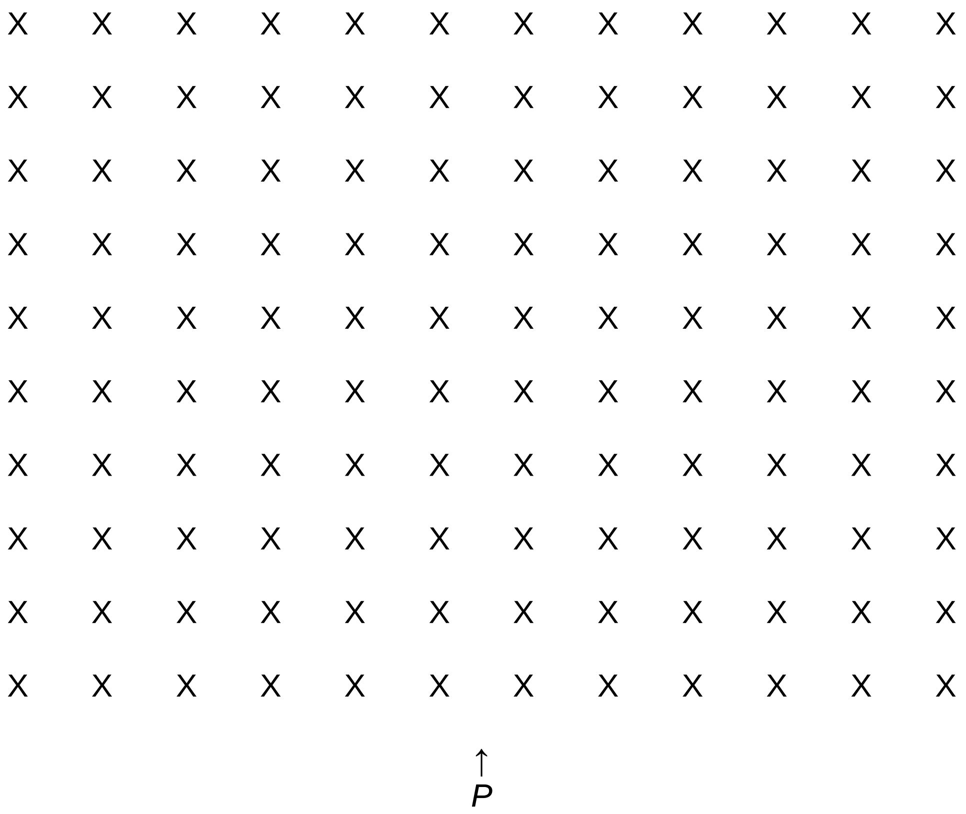
(b) Muons travel at almost the speed of light. Calculate the average distance that a muon created in the upper atmosphere would travel before it decayed. Assume that its speed is equal to c and that there are no relativistic effects. (2 marks)

(c) Muons created by cosmic rays in the upper atmosphere can be detected by detectors on the Earth's surface. This means that the muons have travelled much further than expected. An explanation of this phenomenon involves the effects of relativity.

Explain how relativity affects the muons and enables them to travel over a greater distance than that calculated in (b). (3 marks)

(d) Express the rest mass of a muon in kilograms, and compare this to the rest mass of a proton. (3 marks)

(e) On the diagram below sketch and label two lines representing the paths you would expect a proton and a muon to follow in the given magnetic field. Assume both particles are injected into the field at P with the same velocity. (3 marks)



(f) Injecting and directing a charged particle using magnetic and electric fields is a commonly-used phenomenon. It is used in old (cathode ray tube) television technology as well as in high technology applications such as the CERN Large Hadron Collider.

Using formulae from your Formulae and Constants Sheet, show the derivation of the formula below that determines a particle's velocity from its mass (m) and charge (q), having been accelerated through a potential difference (V). You must show all steps.

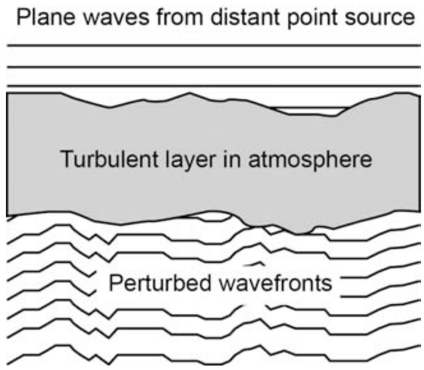
(4 marks)

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

Question 23 **(17 marks)**

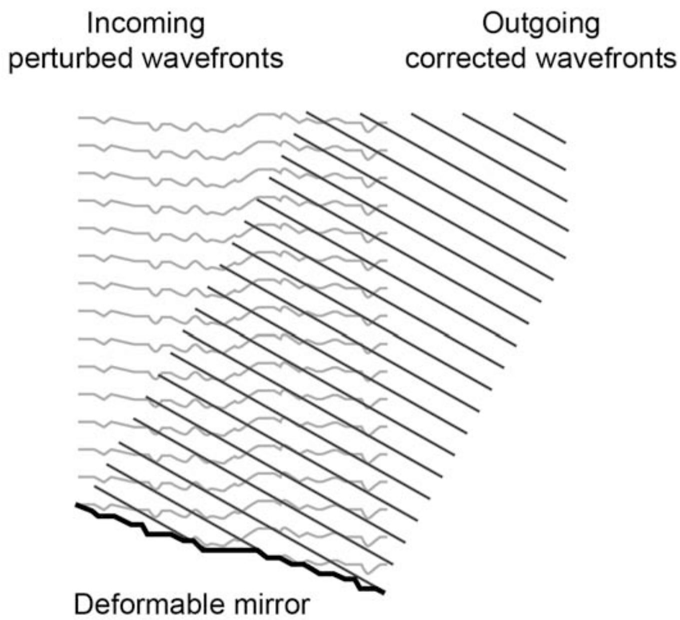
Adaptive Optics and Laser Guide Star

Telescopes with very large mirrors can gather a lot of light to allow viewing of dim, distant astronomical objects. As light waves pass through the atmosphere, tiny variations in the refractive index of the atmospheric gases distort the light's path, causing stars to appear to change position and twinkle. Large-diameter mirrors with fixed focal points thus suffer from image distortion when the position of an astronomical object seems to be in many different places when viewed from different places on the mirror.



Optical wave fronts from an astronomical object may be distorted by a layer of turbulence in the atmosphere. The amount of distortion has been exaggerated.

Adaptive optics is a technology used to improve the performance of large telescopes by reducing the effect of wavefront distortions caused by atmospheric distortion. Adaptive optics works by measuring the distortions in a wavefront and compensating for them with a deformable mirror. This requires a wavefront reference source to allow the telescope to correct the distortion of light caused by turbulence in the atmosphere. Turbulence changes the refractive index of the atmosphere in unpredictable ways. Monitoring the apparent motions of a bright star with known optical characteristics can provide a reference for adaptive optics. When the atmosphere's effects are subtracted, using a deformable tip-tilt mirror, the astronomical image produced is steady and clear.



A deformable mirror can correct distorted incoming wavefronts.

Many parts of the sky lack stars bright enough to use for judging atmospheric conditions. This limits the effectiveness of adaptive optics that use natural guide stars. A laser guide star is an artificial star-like light source created by shining a laser into the upper atmosphere. Such an artificial 'star' can be positioned anywhere that the astronomer wishes to observe, allowing any part of the sky to be viewed using adaptive optics.

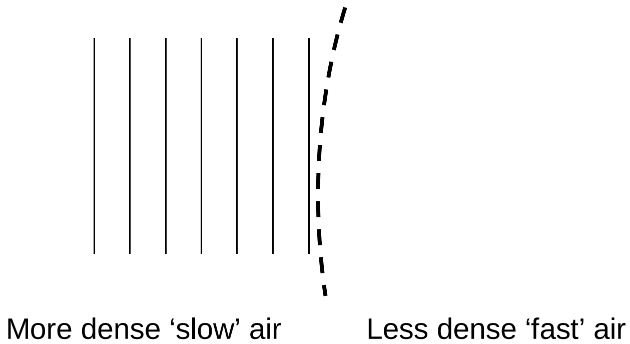
The bright line is a laser beam visible only because of atmospheric scattering.

A 'sodium beacon' is one type of laser guide star. It is created by shining a laser tuned to 589 nm (nanometres) into the upper atmosphere, exciting a naturally-occurring layer of sodium atoms at an altitude of about 90 km. The excited sodium atoms quickly decay, re-emitting the 589 nm light and giving the appearance of a glowing star.

Often, the laser is pulsed and the light from the laser guide star is measured a very short time after the pulse is emitted. This eliminates errors from scattered light at ground level, so that only light that has travelled down from the sodium layer is actually detected. The light returning from the sodium beacon, having travelled through most of the atmosphere, appears to have moved around in the sky in the same way as the light from astronomical objects.

(a) The following diagram shows light wavefronts moving from more dense air, where it moves slower, to less dense air, where it travels faster. Complete the diagram by sketching four more wave fronts in the less dense air.

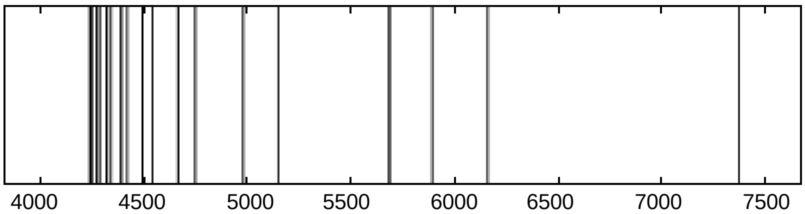
(2 marks)



(b) Calculate the time taken for a pulse from a laser to reach the sodium layer and for the re-emitted light to return to the Earth's surface. Assume that the decay time of excited sodium atoms is negligible. (3 marks)

(c) Calculate the energy in electron volts of a photon of light produced by the sodium beacon laser. (3 marks)

(d) When white light is shone through a gas consisting of sodium atoms and then passed through a prism, the white light's visible spectrum has several dark lines appear, as shown below. The scale is in angstroms ($\times 10^{-10}$ m). (4 marks)



(i) What type of spectrum is this considered to be? ______________________

(ii) Circle the part of the spectrum that corresponds to the light emitted by a sodium beacon laser.

(iii) Astronomers observe light that has passed through gases, such as in a nebula (a gas cloud in space) or a planet's atmosphere. Explain how the characteristics of this light are used to to determine the composition of the gases.

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Fluorescent angiography is a technique for examining the circulation of blood in the retina of the eye using a dye-tracing method. It involves the injection of sodium fluorescein, which circulates through the whole body, including the eye. The eye is then illuminated using blue light of wavelength 490 nm. The sodium fluorescein fluoresces, emitting yellow-green light that is photographed to create an angiogram.

(e) Using the energy level diagrams below, determine and draw on the diagrams the photon absorption and emission transitions for:

A the sodium beacon laser guide star

and

B the fluorescent angiography. You must show the calculations used for determining the absorption transition.

The energy level diagrams are simplified. A sodium atom has many energy level transitions available and therefore not all energy levels are shown. (5 marks)

A Laser guide star transitions		**B** Fluorescent angiography transitions
3.6 eV		3.6 eV
3.2 eV		3.2 eV
2.5 eV		2.5 eV
2.1 eV		2.1 eV
0 eV		0 eV

End of questions