

Surname	Centre Number	Candidate Number
Other Names		2



GCE A level

1325/01

**PHYSICS – PH5
ASSESSMENT UNIT
Electromagnetism, Nuclei & Options**

A.M. THURSDAY, 19 June 2014

1 hour 45 minutes

ADDITIONAL MATERIALS

In addition to this paper, you will require a calculator, a **Case Study Booklet** and a **Data Booklet**.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use pencil or gel pen. Do not use correction fluid.

Write your name, centre number and candidate number in the spaces at the top of this page.

Write your answers in the spaces provided in this booklet. If you run out of space, use the continuation pages at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

This paper is in 3 sections, **A**, **B**, and **C**.

Section A: 60 marks. Answer **all** questions. You are advised to spend about 1 hour on this section.

Section B: 20 marks. The Case Study. Answer **all** questions. You are advised to spend about 20 minutes on this section.

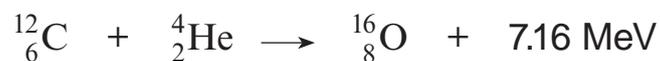
Section C: Options; 20 marks. Answer **one option only**. You are advised to spend about 20 minutes on this section.



J U N 1 4 1 3 2 5 0 1 0 1

SECTION A*Answer all questions.*

1. (a) Carbon fuses with helium to produce oxygen and energy.



The masses of the helium and carbon nuclei are 4.0015 u and 11.9967 u respectively.

- (i) Calculate the binding energy **per nucleon** of the carbon nucleus ($1 \text{ u} = 931 \text{ MeV}$, $m_{\text{proton}} = 1.0073 \text{ u}$, $m_{\text{neutron}} = 1.0087 \text{ u}$). [3]

.....

.....

.....

.....

.....

.....

- (ii) Use the energy released in the above reaction to calculate the mass of the oxygen-16 nucleus to 6 significant figures. ($1 \text{ u} = 931 \text{ MeV}$.) [4]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



(b) It is important to choose suitable materials inside a nuclear fission reactor to act as control rods, moderator and coolant. Name **one important property of the materials** used for the:

(i) control rods; [1]

.....

(ii) moderator; [1]

.....

(iii) coolant. [1]

.....



2. (a) Radon gas ($^{222}_{86}\text{Ra}$) is radioactive and can be a significant health hazard in areas that have a high natural concentration of the gas. Radon decays to a stable form of lead (Pb) via 4 alpha decays and 4 beta decays and radon has a half-life of 3.8 days.

(i) Calculate the mass number and atomic number of this stable isotope of lead (Pb). [2]

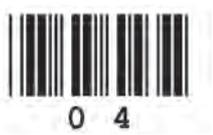
.....
.....
.....
.....

(ii) Give **three** reasons why radon gas is particularly dangerous. [3]

.....
.....
.....
.....
.....
.....

(b) Calculate the time taken for the number of radon gas particles to decrease to 9.0% of their initial number. [4]

.....
.....
.....
.....
.....
.....



- (c) When radon gas is kept in a lead lined container for 3.8 days, the number of radon gas particles halves. However, the activity inside the container is considerably higher than half the original activity. Suggest a reason why. [1]

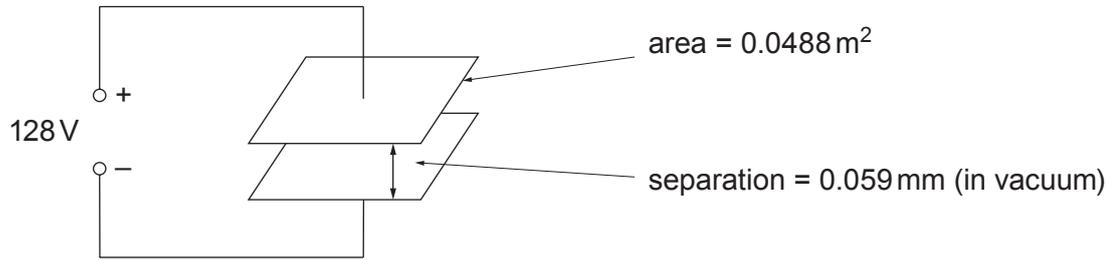
.....

.....

.....



3. (a)



(i) Calculate the charge stored by the capacitor. [3]

.....

.....

.....

.....

.....

(ii) Use (a)(i) to calculate the energy stored by the capacitor. [1]

.....

.....

.....

(iii) Calculate the electric field strength (E) between the plates. [2]

.....

.....

.....



(b) After the capacitor is charged it is isolated from the power supply so that the charge stored **remains constant**. Then the plates are pulled further apart.

(i) Explain what happens to the capacitance of the capacitor and hence the energy stored by the capacitor. [2]

.....

.....

.....

.....

.....

(ii) Explain how energy is conserved in this case. [2]

.....

.....

.....

.....



4. (a) A long solenoid of length 1.45 m has 9 560 turns. Calculate the magnetic field strength (B) inside the solenoid when it carries a current of 320 mA. [2]

.....

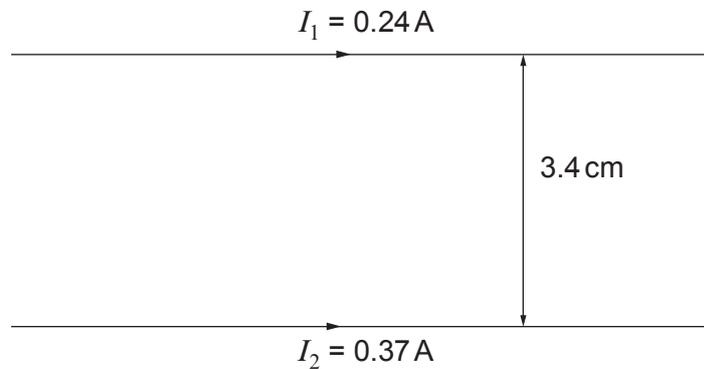
.....

.....

.....

.....

- (b) Calculate the resultant magnetic field strength (B) half way between the two long wires shown and **state its direction**. [4]



.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



(c) Calculate the position between the two wires where the magnetic field strength is zero. [3]

.....

.....

.....

.....

.....

.....

.....

.....

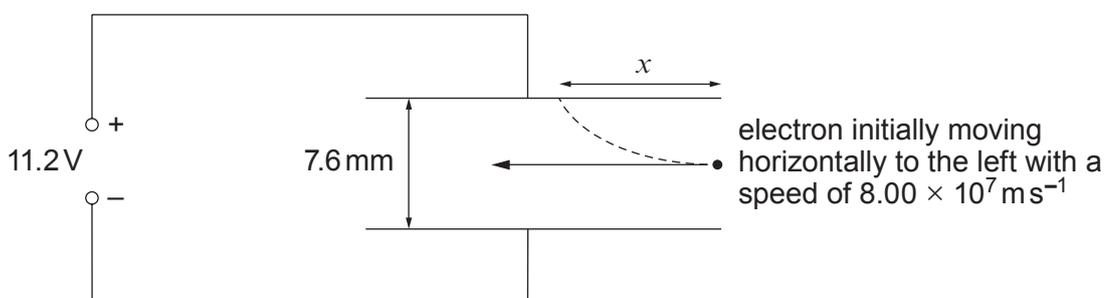
.....

.....

1325
010009



5. An electron enters the uniform electric field **half way** between the plates of a capacitor as shown. The electron is travelling in a vacuum.



- (a) Show that the vertical acceleration of the electron is approximately $2.6 \times 10^{14} \text{ m s}^{-2}$. [4]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

- (b) (i) Explain why the **horizontal speed** of the electron remains constant. [1]

.....

.....

.....

- (ii) Explain why the vertical **acceleration** of the electron is constant. [1]

.....

.....

.....



(c) The electron enters the plates and travels a horizontal distance x before hitting the top plate (see diagram). Calculate x . [3]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(d) Calculate the **extra** kinetic energy gained by the electron before striking the plate. [2]

.....

.....

.....

.....

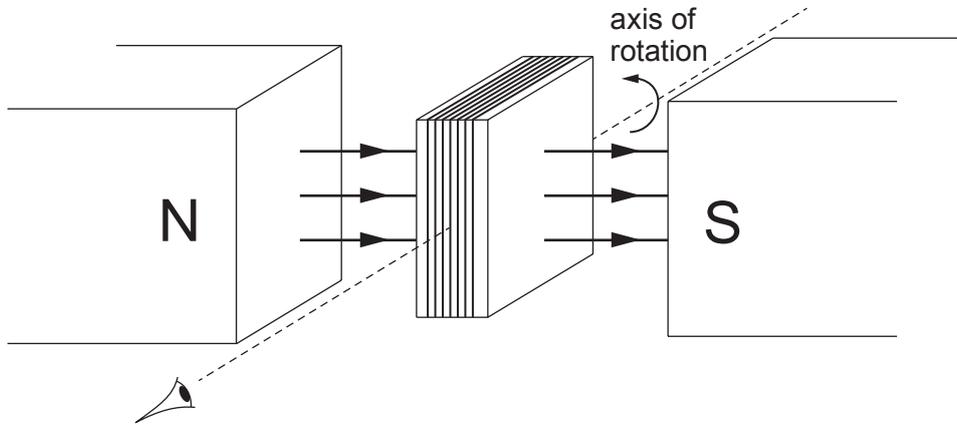
.....

.....

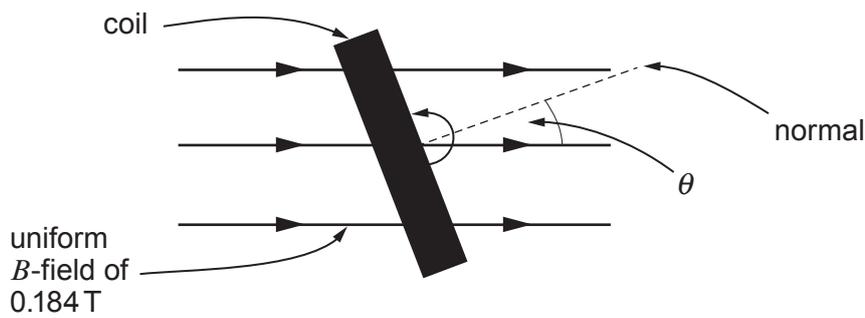
1325
010011



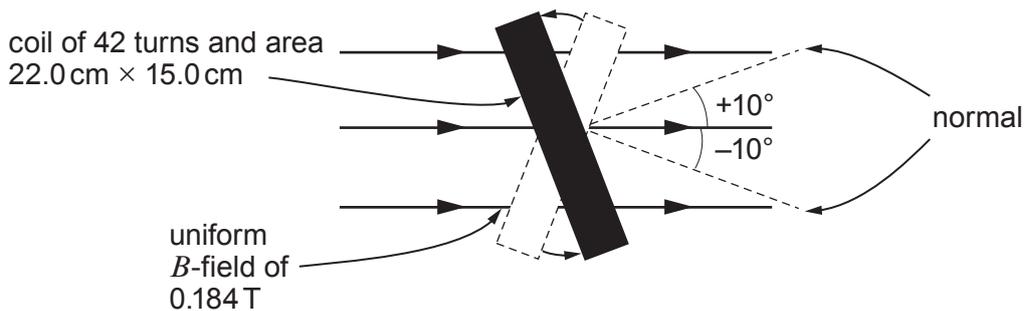
6. A rectangular coil rotates at a constant angular velocity within a uniform magnetic field. The coil has 42 turns and area $22.0\text{ cm} \times 15.0\text{ cm}$. The diagram below is a simplified 3D diagram of the coil when the magnetic field is perpendicular to the coil.



The second diagram is a 2D representation of the coil looking along the axis of rotation.



- (a) (i) Calculate the flux **linkage** of the coil for the angles $\theta = -10^\circ$ and $\theta = +10^\circ$. [2]



.....

.....

.....

.....



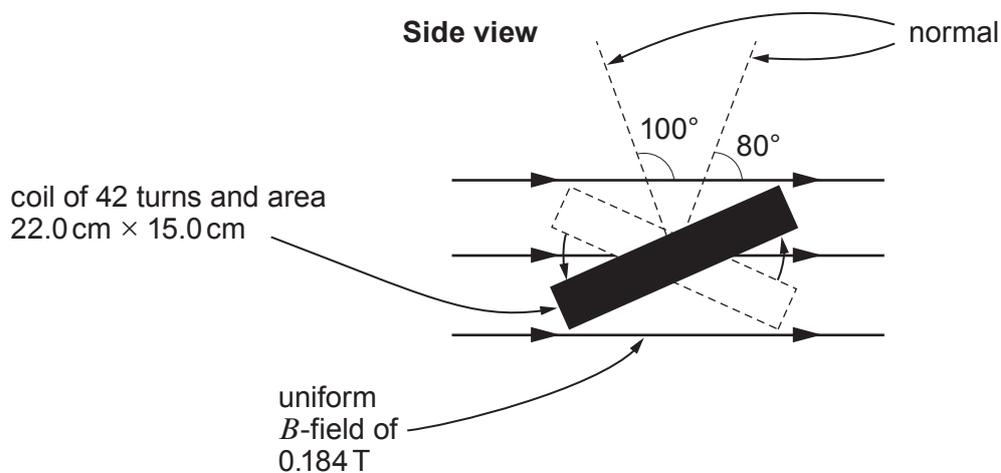
- (ii) Explain why the mean induced emf is zero as the coil moves between $\theta = -10^\circ$ and $\theta = +10^\circ$. [1]

.....

.....

.....

- (b) Calculate the mean induced emf in the coil when the angle θ changes from 80° to 100° if the period of rotation of the coil is 0.100 s. [4]



.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



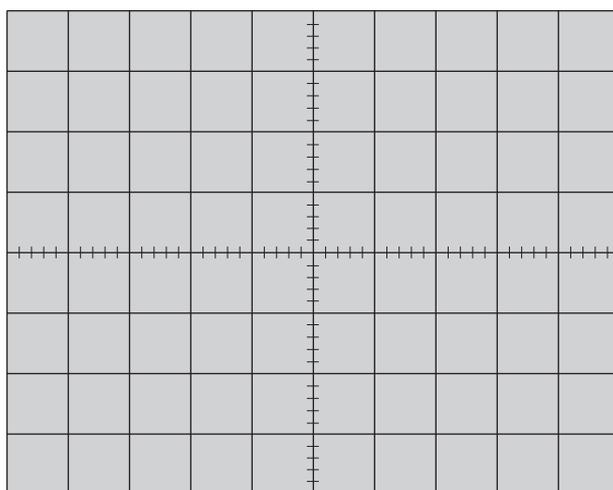
- (c) An oscilloscope is used to display the sinusoidal emf in a different coil rotating at a frequency of 12.5 Hz and producing an **rms** pd of 12.0 V. The oscilloscope settings are 5 V per division (vertically) and 20 ms per division (horizontally). Sketch a trace that might be seen on the oscilloscope. (Space is provided for your workings.) [3]

.....

.....

.....

.....



SECTION B

Answer all questions.

The questions refer to the case study.
Direct quotes from the original passage will not be awarded marks.

- 7. (a) Explain briefly how parallax is used to measure the distances of stars from the Earth. (See paragraph 1.) [2]

.....

.....

.....

.....

.....

.....

- (b) The parallax angle for a certain star is measured as 0.25 arcseconds. Calculate the distance of the star in light years. (See paragraph 4.) [2]

.....

.....

.....

- (c) Consider two stars of equal absolute magnitude the first at a distance of 1 parsec and the second at a distance of 10 parsec. Use the equation $M = m + 5(1 + \log_{10} p)$ to confirm that 'a difference of 5 magnitudes is defined as being equivalent to a factor of 100 in brightness'. (See paragraphs 7 and 8.) [3]

.....

.....

.....

.....

.....

.....

- (d) What percentage of the Universe is not hydrogen or helium? (See paragraph 10.) [1]

.....

.....

1325
010015



- (e) In your own words, explain why absorption corresponding to the Paschen series does not occur in relatively cold stars. (See paragraphs 11 and 12.) [3]

.....

.....

.....

.....

.....

.....

- (f) Calculate a value for the constant, b , in the equation $L = br^2T^4$ and give its unit. (See paragraph 15.) [3]

.....

.....

.....

.....

.....

.....

- (g) (i) Show that the equation $(M + m)T^2 = a^3$ is valid for the orbit of the Earth around the Sun. (See paragraph 16.) [1]

.....

.....

.....

- (ii) A small planet orbits a star that has a mass $0.32 M_{\text{Sun}}$ and its period of orbit is found to be 0.46 year. Estimate the planet's distance from its star stating any approximation that you make. [2]

.....

.....

.....

.....



(h) Explain the intensity variation with respect to time shown in the diagram for the eclipsing binary star. (See paragraph 21.) [3]

.....

.....

.....

.....

.....

.....

1325
010017



SECTION C: OPTIONAL TOPICSOption A: **Further Electromagnetism and Alternating Currents**Option B: **Revolutions in Physics – Electromagnetism and Space–Time**Option C: **Materials**Option D: **Biological Measurement and Medical Imaging**Option E: **Energy Matters**

Answer the question on **one topic only**.

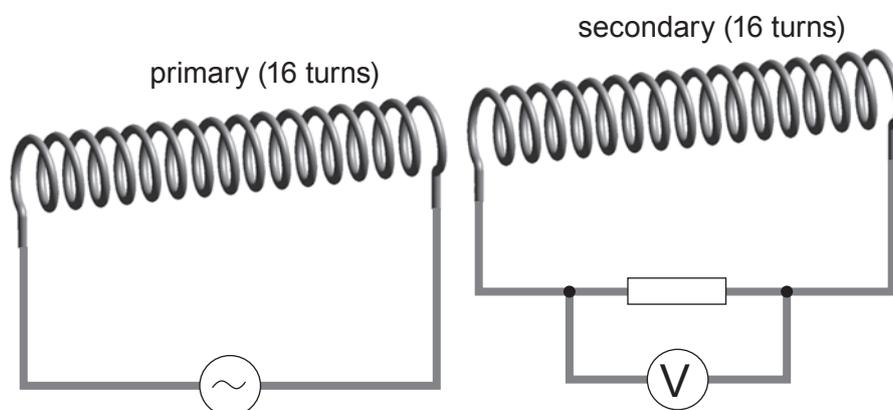
Place a tick (✓) in one of the boxes above, to show which topic you are answering.

You are advised to spend about 20 minutes on this section.



Option A: Further Electromagnetism and Alternating Currents

8. (a) A sinusoidal pd of 6 V (rms) and frequency 0.9 Hz is supplied to the primary solenoid.



- (i) State how the reading on the voltmeter varies and explain what causes the voltmeter reading to vary. [4]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

- (ii) Give a reason why the rms pd measured by the voltmeter will be much lower than 6 V. [1]

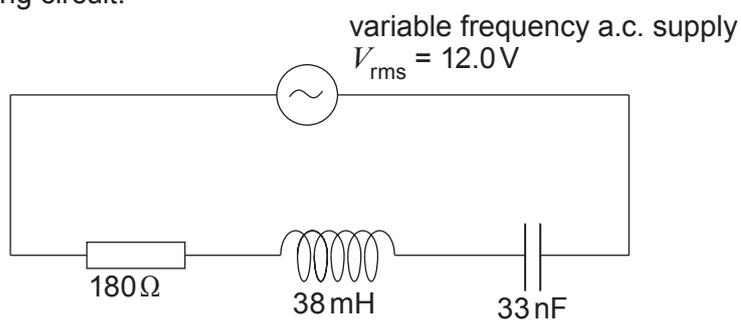
.....

.....

.....



(b) For the following circuit:



(i) calculate the resonance frequency; [2]

.....

.....

.....

.....

(ii) calculate the rms pd across each component at resonance. [4]

.....

.....

.....

.....

.....

.....

.....

(c) The frequency of the a.c. supply is now set to 5.8 kHz.

(i) Calculate the rms current. [3]

.....

.....

.....

.....

.....

.....

.....



- (ii) Calculate the phase angle between the current and the applied pd (a phasor diagram may assist your calculation). [3]

.....

.....

.....

.....

.....

.....

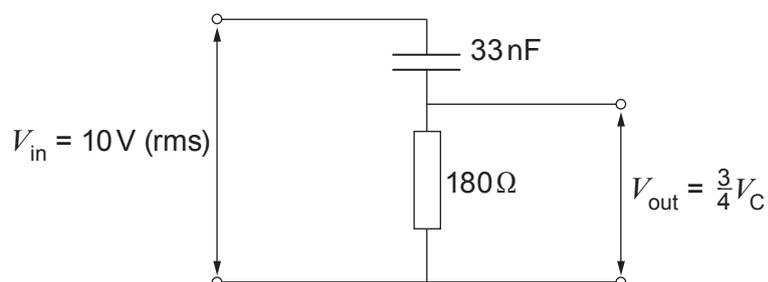
.....

.....

.....

.....

- (d) In the high pass filter shown the rms output pd is $\frac{3}{4}$ of the rms pd across the capacitor.



Calculate the frequency of the input pd. [3]

.....

.....

.....

.....

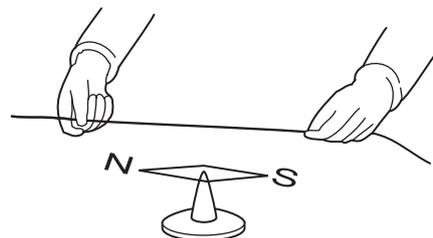
.....

.....



Option B: Revolutions in Physics – Electromagnetism and Space–Time

9. A sketch is given of the apparatus used in a famous experiment of 1820, showing the magnetic effects of an electric current.



- (a) (i) Who performed the experiment? [1]

.....

- (ii) Part of the apparatus (not shown) was a voltaic pile. What is the modern name for a voltaic pile? [1]

.....

- (iii) Describe what was done in the experiment, what was observed and what conclusion was reached about the magnetic field due to the current. [3]

.....

.....

.....

.....

.....

.....

.....

- (iv) The experiment and its results inspired Faraday to start a search which led to his discovery of electromagnetic induction. What was Faraday searching for? [1]

.....

.....

- (b) (i) Explain how a magnetic field is represented in Maxwell's vortex ether. Include a labelled diagram of a region containing four vortices. [3]

.....

.....



(ii) Maxwell wrote about his vortex ether:

“The conception of a particle having its motion connected with that of a vortex by perfect rolling contact may appear somewhat awkward. I do not bring it forward as a mode of connexion existing in nature, or even as that which I would willingly assent to as an electrical hypothesis. It is, however, a mode of connexion which is mechanically conceivable, and easily investigated, and it serves to bring out the actual mechanical connexions between the known electro-magnetic phenomena [...]”

Discuss briefly whether or not the vortex ether served its purpose, even though few physicists – if any – would argue for its existence. [2]

.....

.....

.....

.....

.....

.....

(c) Describe briefly how Hertz:

(i) produced electromagnetic waves and how he detected them; [2]

.....

.....

.....

.....

(ii) confirmed the transverse nature of the waves; [1]

.....

.....

.....

(iii) measured the wavelength. [2]

.....

.....

.....



- (d) (i) State what is meant by a *proper time interval* between two events. [1]

.....

.....

.....

- (ii) A spacecraft travels between two space stations, A and B, at a speed of $0.140c$ (that is $4.20 \times 10^7 \text{ m s}^{-1}$). A clock on board the spacecraft records the journey time from A to B as 50.0 s .

Synchronised clocks in the space stations A and B record the spacecraft passing them at times t_A and t_B . Calculate the time interval $(t_B - t_A)$. [Assume A and B to be in fixed positions in an inertial frame.] [3]

.....

.....

.....

.....

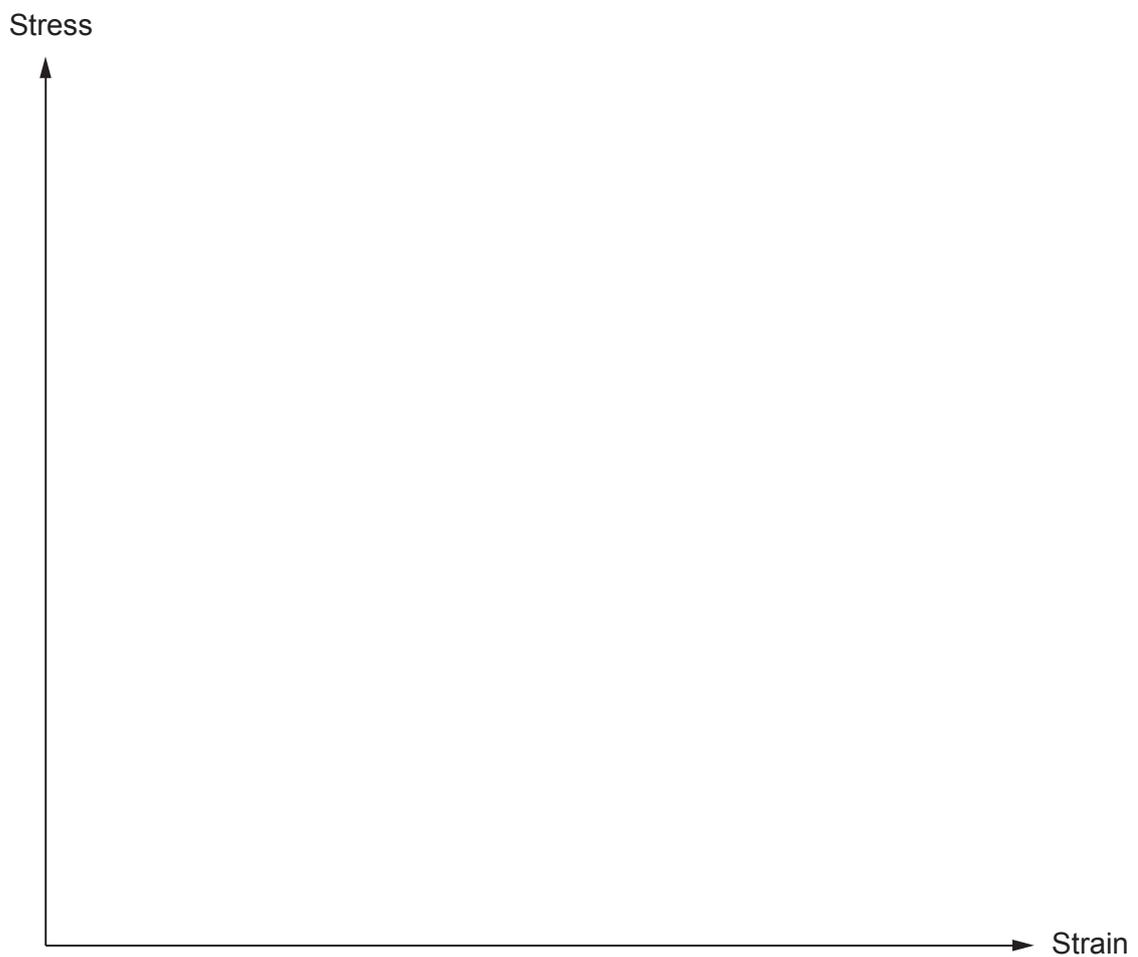
.....

.....

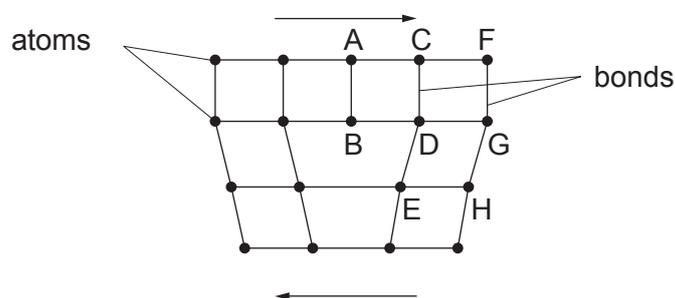


Option C: Materials

10. (a) Sketch a typical stress-strain graph for the stretching to breaking point of a ductile metal such as copper. Label on your graph:
- (i) the elastic limit;
 - (ii) the yield point;
 - (iii) the region of plastic deformation;
 - (iv) the breaking point.
- [6]



- (b) The diagram shows the arrangement of atoms in a metal crystal in the region of a dislocation.



- (i) Using the letters in the diagram, explain how plastic deformation takes place in ductile metals when forces are applied as shown by the arrows. Space is provided so that you can illustrate your answer if you wish to do so (or you may add to the existing diagram). [3]

.....

.....

.....

.....

- (ii) 'Superalloys' in the form of single crystals have recently been developed to withstand extreme conditions of temperature and pressure. **In terms of atomic structure**, give one reason why superalloys can withstand higher temperatures and pressures than conventional multi-crystal alloys. [1]

.....

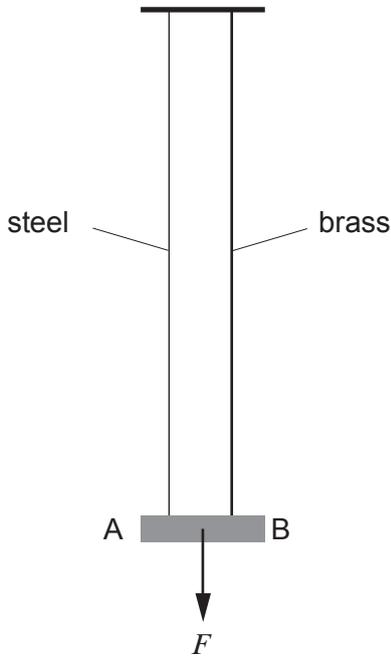
.....

- (iii) State one application of 'superalloys'. [1]

.....



- (c) A light bar (AB) is suspended horizontally from two vertical wires, one of steel and one of brass as shown in the diagram. Each wire is of the same length, though their cross-sectional areas (A_{brass} and A_{steel}) are different. When a force F is applied to the **centre** of AB the wires **extend by an equal amount** and the bar remains horizontal.



- (i) Given that the Young modulus of steel is $2.0 \times 10^{11} \text{ N m}^{-2}$, and that of brass is $1.0 \times 10^{11} \text{ N m}^{-2}$, show clearly that $A_{\text{brass}} = 2A_{\text{steel}}$. [2]

.....

.....

.....

.....

- (ii) Determine the tension in each wire when $F = 100 \text{ N}$. [1]

.....

- (iii) Hence calculate the extension in the steel wire when $F = 100 \text{ N}$. The initial length of wire is 2.0 m and its cross-sectional area is $2.8 \times 10^{-7} \text{ m}^2$. [2]

.....

.....

.....

- (iv) Calculate the energy stored in the steel wire when $F = 100 \text{ N}$. [2]

.....

.....

- (v) Without further calculation, comment on the energy stored in the brass wire when $F = 100 \text{ N}$ and justify your answer. [2]

.....

.....

.....

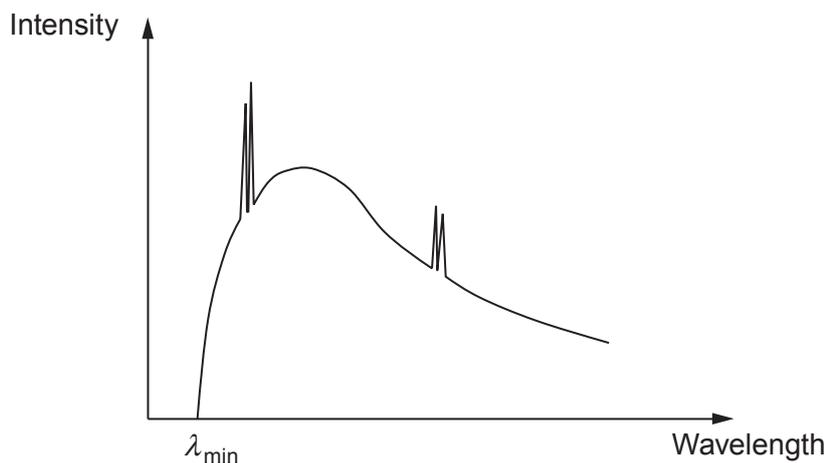
.....



Option D: Biological Measurement and Medical Imaging

11. The diagram below shows a typical intensity spectrum for the output of an X-ray tube using a tungsten target.

- (a) (i) Label the **background spectrum** and the **line spectrum**. [1]



- (ii) Explain clearly how each of the two spectra is produced; [4]

(I) line spectrum;

.....

.....

.....

.....

.....

.....

.....

(II) background spectrum.

.....

.....

.....

.....

.....

.....

.....



(iii) If the X-ray tube is operated at an accelerating pd of 60 kV calculate the minimum wavelength of an X-ray photon emitted from the tube. [2]

.....

.....

.....

.....

.....

.....

(b) You have the choice of the following forms of medical imaging:

X-ray ultrasound A-scan ultrasound B-scan MRI scan CT scan

Which of the above would be the most suitable to image the following? Give a reason for each answer. [6]

(i) The development of an unborn baby.

.....

.....

.....

.....

(ii) A lung tumour in a patient who wears a pacemaker (metal container).

.....

.....

.....

.....

(iii) A brain tumour in an adult patient.

.....

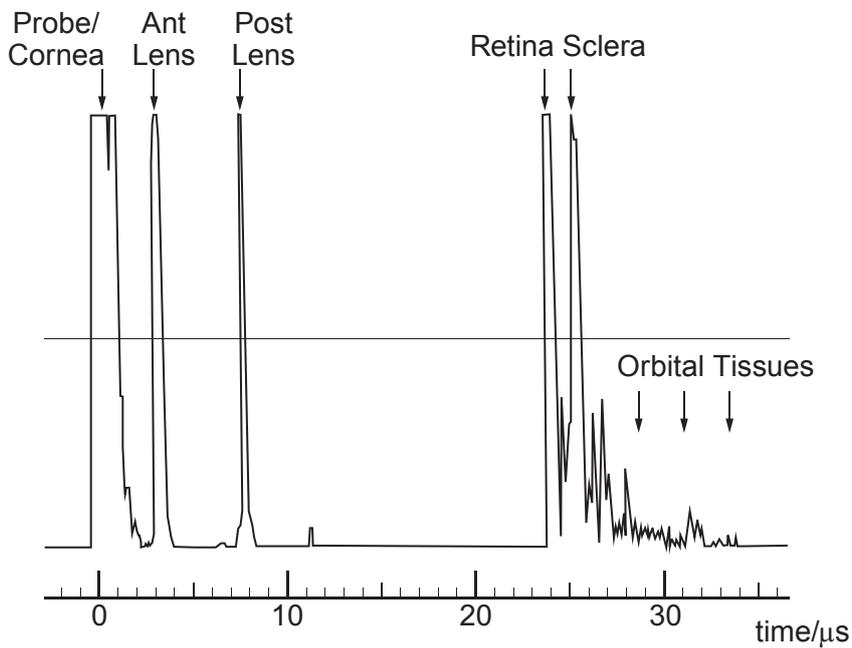
.....

.....

.....



(c) Ultrasound A-scans can be used on the human eye in order to obtain accurate measurements of the thickness of the lens. Below is a copy of such a scan.



Use the information in the diagram to calculate the lens thickness. The spike labelled 'Ant Lens' corresponds to the front of the lens and the spike labelled 'Post Lens' corresponds to the back of the lens. The velocity of ultrasound in the lens is 1640 ms^{-1} . [3]

.....

.....

.....

.....

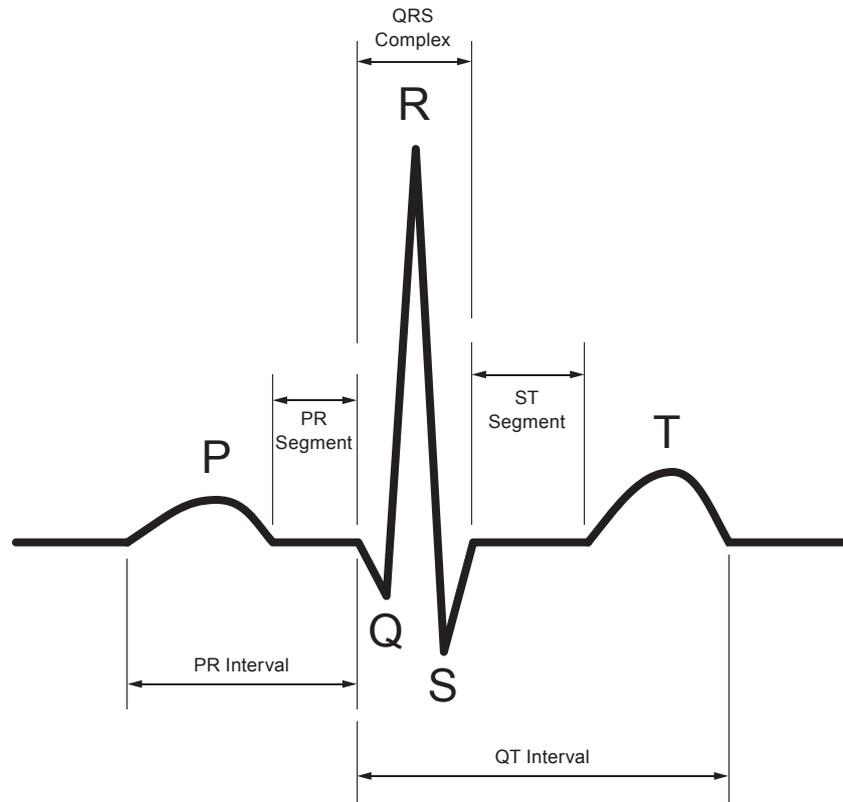
.....

.....

.....



(d) The diagram below shows an ECG trace for a healthy person.



What changes would you expect to the above pattern if:

(i) a person had high blood pressure due to the ventricles working too hard; [2]

.....

.....

.....

(ii) the atrium was not contracting properly; [1]

.....

.....

.....

(iii) the ECG trace was taken for a person who had recently had a mild heart attack (myocardial infarction MI)? [1]

.....

.....

.....



Option E: Energy matters

12. One possible scheme to decrease CO₂ emissions for the UK is to build a Severn barrage and to use the twice daily motion of tidal water in the Bristol channel for electricity production.



- (a) Discuss briefly two points:
- (i) in favour of this scheme (note that merely stating: 'to decrease CO₂ emissions' will not be enough for a mark); [2]

.....

.....

.....

.....

.....

.....

.....

.....

.....



(ii) against this scheme.

[2]

.....

.....

.....

.....

.....

.....

.....

.....

(b) Write down the two energy **conversions** associated with this scheme.

[2]

.....

.....

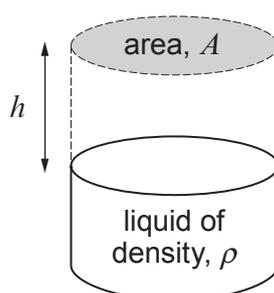
.....

(c) A column of liquid of density, ρ , has an area, A . The column is increased in height by a distance, h (see diagram). Show that the increased potential energy is given by:

$$PE = \frac{1}{2} A\rho gh^2$$

where g is the acceleration due to gravity.

[3]



.....

.....

.....

.....

.....



(d) The mean tidal height (h) in the Severn estuary is 14 m, the area of water the proposed scheme covers is 140km^2 , the density of sea water is 1025kgm^{-3} and there are approximately 2 high tides every day. Estimate the average power output of the scheme assuming an efficiency of 75%. [4]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(e) (i) Another scheme has been proposed without the need to trap the water at high tide. This would employ turbines rotating almost continually as the tide flows in both directions. State the **two** main advantages of this type of scheme. [2]

.....

.....

.....

.....

.....

.....

.....



BLANK PAGE

**PLEASE DO NOT WRITE
ON THIS PAGE**



BLANK PAGE

**PLEASE DO NOT WRITE
ON THIS PAGE**



BLANK PAGE

**PLEASE DO NOT WRITE
ON THIS PAGE**





GCE A level

1325/01-B

**PHYSICS – PH5
ASSESSMENT UNIT**

A.M. THURSDAY, 19 June 2014

**CASE STUDY FOR USE WITH
SECTION B**

Examination copy

To be given out at the start of the examination.

The pre-release copy must not be used.

1325
01B001

How do we measure the properties of stars?

(freely adapted from Elementary Astronomy lecture course given at Pennsylvania State University, original notes written by Professor Robin Ciardullo).

Parallax is rather a useful effect when studying stars, it can tell us how close the nearest stars are. The motion of the Earth around the Sun provides the parallax and we can measure the parallax angle. For the nearest stars, this angle is about one arcsecond, that is, $\frac{1}{60}$ of $\frac{1}{60}$ of one degree ($\frac{1}{3600}$ of a degree). For comparison, the angular size of the Moon is $\frac{1}{2}$ of a degree. Thus, if you divide the Moon into 1800 pieces, you'll get 1 arcsecond.

Through the trigonometry of the extremely skinny triangle on the right, we can then measure a distance.

Astronomers always try to make things as easy as possible for themselves. They define a new unit of distance, called the **parsec**.

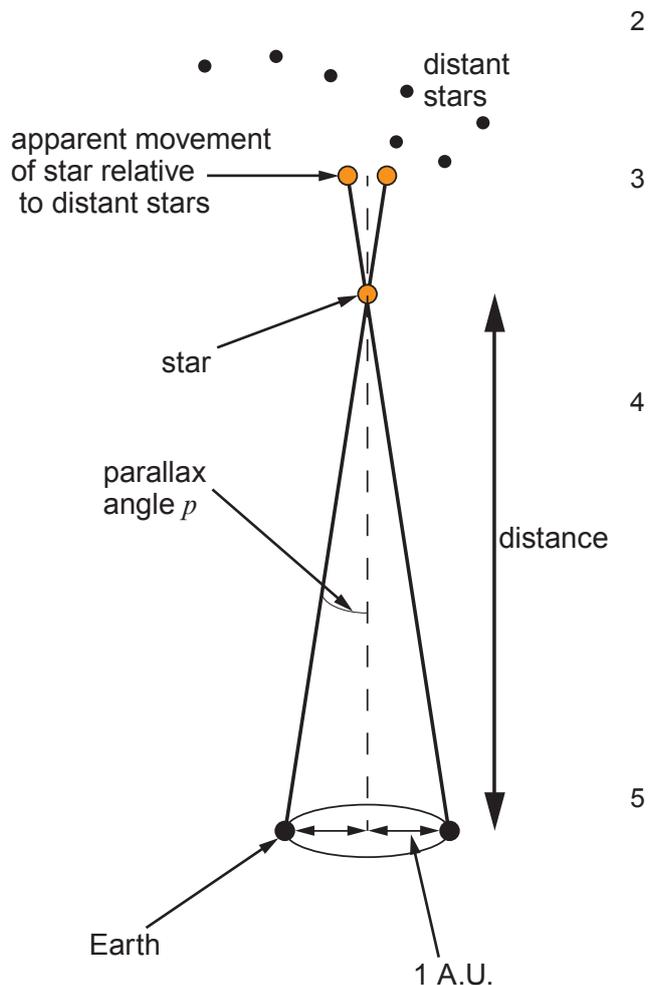
One parsec is **the distance a star would have if it had a parallax angle of 1 arcsecond**. (For those who insist on numbers, it's about 206 265 Astronomical Units, or 3×10^{13} km or 3.25 light years.) Note that by defining a parsec in this way, the relationship between the measured parallax angle and the implied distance is trivial. If a star has a parallax of 1 arcsec, its distance is 1 parsec. If it has a parallax of $\frac{1}{2}$ arcsec its distance is 2 parsec. If it has a parallax of $\frac{1}{10}$ arcsec, its distance is 10 parsecs. And so on.

If we measure the distance to a star, and we measure how bright a star appears in the sky, we can then figure out the star's intrinsic brightness i.e. how bright the star really is. (Is the star a matchstick in front of our eyes, or a searchlight far away?) This is done using the inverse square law of light, which relates the intrinsic luminosity, L to its apparent luminosity I by:

$$I = \frac{L}{r^2} \quad \text{where } r \text{ is the distance.}$$

Astronomers don't measure brightness in terms of watts (or even gigawatts). Sometimes they use **solar luminosities**, which is how bright a star is compared with the Sun. (For reference, the Sun is equivalent to a 4×10^{26} W light bulb!) More often (unfortunately), they use **absolute magnitude**.

Apparent magnitude describes how bright a star appears in the sky. Vega's apparent magnitude is defined as zero. Deneb's apparent magnitude is close to 1; Polaris (the North Star) is close to 2. The faintest star you can generally see has an apparent magnitude of around 3 or 4. The faintest star you can see out in the desert far from the lights of a city has an apparent magnitude of 6. Note that the magnitude scale goes backward – big numbers represent faint stars. Also note that magnitude scale works the way the human eye does,



which is logarithmically. This means that each magnitude is 2.5 times fainter than the previous magnitude. A star with apparent magnitude $m = 1$ is 2.5 times fainter than a star with $m = 0$. A star with $m = 2$ is $2.5 \times 2.5 = 6.25$ times fainter than one with $m = 0$. And so on. In fact, a difference of 5 magnitudes is defined as being equivalent to a factor of 100 in brightness.

The apparent magnitude of a star describes how bright the star appears. The absolute magnitude of a star describes the star's intrinsic brightness. Absolute magnitude is defined in this way – **a star's absolute magnitude is the apparent magnitude the star WOULD have IF it were at a distance of 10 parsec.** The Sun has an apparent magnitude of -26 . However, if the Sun were 10 parsecs away from the Earth, it would be much fainter; its apparent magnitude would be about 5 (you wouldn't normally be able to see it). So the Sun's absolute magnitude is 5. For stars other than the Sun, the formula that relates apparent magnitude, absolute magnitude and parallax angle is:

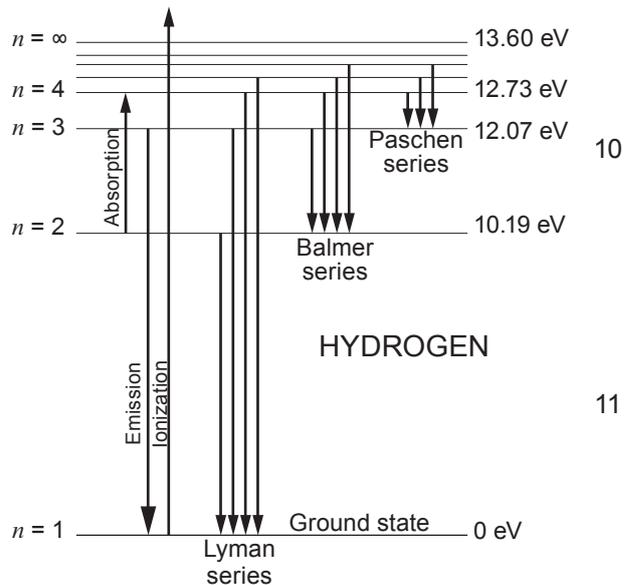
$$M = m + 5(1 + \log_{10} p)$$

where M is the absolute magnitude, m is the apparent magnitude and p is the star's parallax angle in arcseconds.

Stellar surface temperatures are relatively easy to estimate. One way to do this is to estimate the star's colour. The redder the star, the cooler it is; the bluer the star, the hotter it is. But there's another way to measure a star's temperature, which works even when (for one reason or another), the colour method doesn't work well. The method involves looking at the star's spectrum.

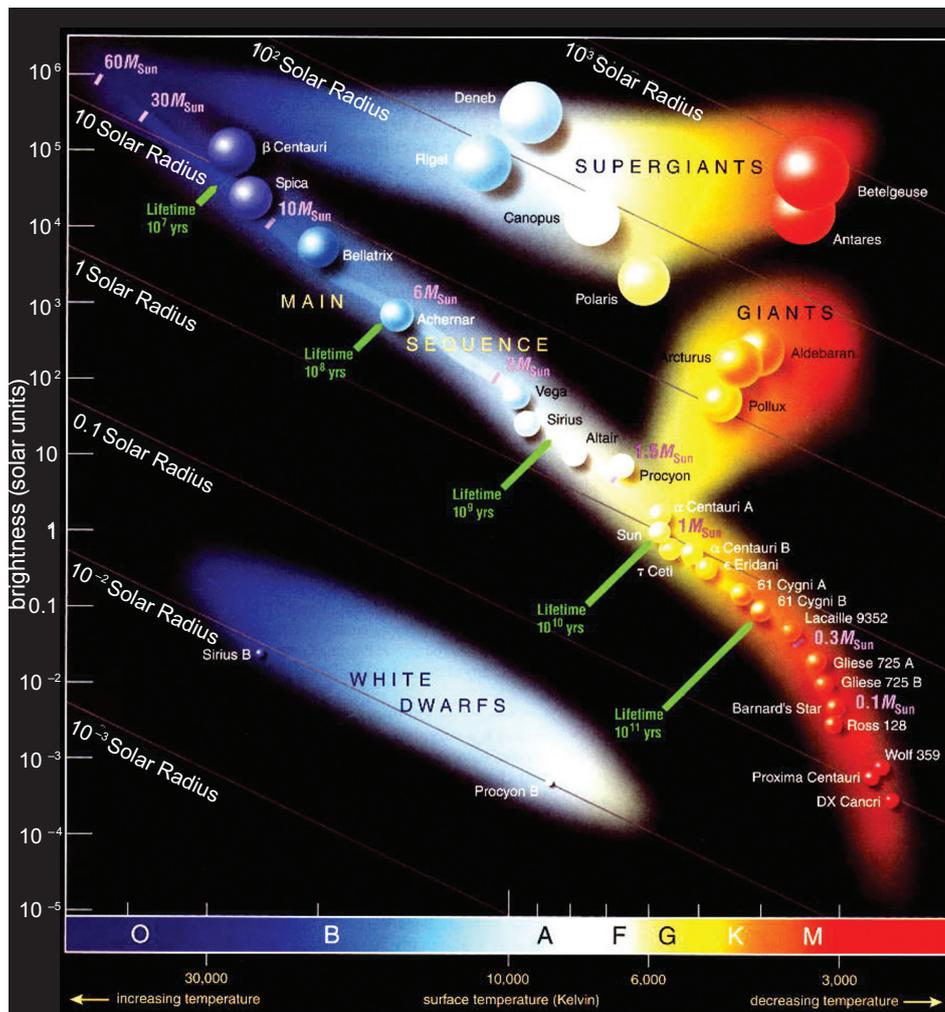
Stars are made mostly of hydrogen and helium. Nine out of ten atoms in the universe are hydrogen atoms. Nine out of ten of what's left is helium. So, when we observe the spectrum of a star, we should see mostly hydrogen and helium. We don't, and the reason comes from the atomic physics of the individual elements.

To understand this, let's consider the hydrogen atom as an example. Like all atoms, hydrogen has multiple levels for its electron. It turns out that for hydrogen, the distance between the first level and the second level is huge – it's equivalent to a far ultraviolet photon. Optical absorptions for hydrogen only occur when an electron in the second level grabs a photon and goes up to a higher level. This atomic structure has an interesting consequence.



Consider hydrogen in the atmosphere of a cool, red star. Virtually all the hydrogen will have its electrons in the ground (lowest) state. In order for one of these electrons to be in the second level, where it can grab an optical photon, it either has to (a) absorb an ultraviolet photon of the proper energy, or (b) be hit by something that has enough energy to push it up. But, in the case of a cool star, there are hardly any ultraviolet photons to absorb, and the atoms are moving so slowly that none of the collisions are hard enough to move an electron to a higher energy level. As a result, in cool stars, there are no hydrogen atoms that have their electrons in the second level, and therefore there are no **optical** absorption lines from hydrogen.

Now consider a very hot star. This hot star emits many high energy photons, and many of these are energetic enough to kick a hydrogen electron completely out of the atom (i.e. to ionize the atom). If all the hydrogen atoms have lost their electrons, then there won't be any hydrogen electrons in the second energy level, and again, there will be no optical absorption from hydrogen. So hot stars, like cool stars, will show no hydrogen absorption lines in the visible range. Thus, if one sees strong hydrogen absorption, the star must be of intermediate temperature (it is strongest at about 10000 degrees).



So far, we have discussed how to derive the intrinsic luminosity of a star and the star's temperature. When astronomers find out two properties of an object (such as a star), the first thing they usually do is plot one versus the other. This is the **Hertzsprung-Russell diagram**, otherwise known as the HR diagram. The x -axis of the HR diagram gives the stars' temperatures (or, equivalently their colour, or spectral type). Because astronomers like to do things backwards, hot blue, O-stars are plotted on the left, and cool, red, M-stars are plotted on the right. The y -axis of the HR diagram gives the stars intrinsic luminosity (or absolute magnitude). Bright stars are at the top of the diagram, cool stars are near the bottom. An

overwhelming majority of stars (more than 90%) fall in a band across the diagram, going from cool and faint to hot and bright. This band is called the **main sequence** and it makes sense. Recall that from the blackbody law, hot objects radiate a lot more energy than cool objects (by temperature to the fourth power). So, it is reasonable that cool stars are faint and hot stars are bright. However, there are some peculiar stars that do not fall on the main sequence. In particular, some stars are both very red and very bright, while others are very blue and very faint. Let's consider the red stars first. Each square metre of these stars must be relatively faint, since cool objects do not radiate much light. The only way that these stars can be bright is to be enormous (i.e. they must have a lot of square metres). We will call these **red giant stars**. Conversely, the only way very hot stars can be faint is to be exceedingly small. These are **white dwarf** stars (though a better name would be blue dwarf stars).

Note that in reality, the brightness of a star depends on two factors: its temperature and how much surface area the star has. In other words:

$$L = br^2T^4 \quad 15$$

where L is the absolute luminosity of the star, r is the star's radius, T is the star's surface temperature, and b is a number to make the units come out all right. Note also that the radius of the star is plotted with a dashed line in the HR diagram – the lower left (blue) of the diagram is small, while the upper right (red) end of the diagram is large.

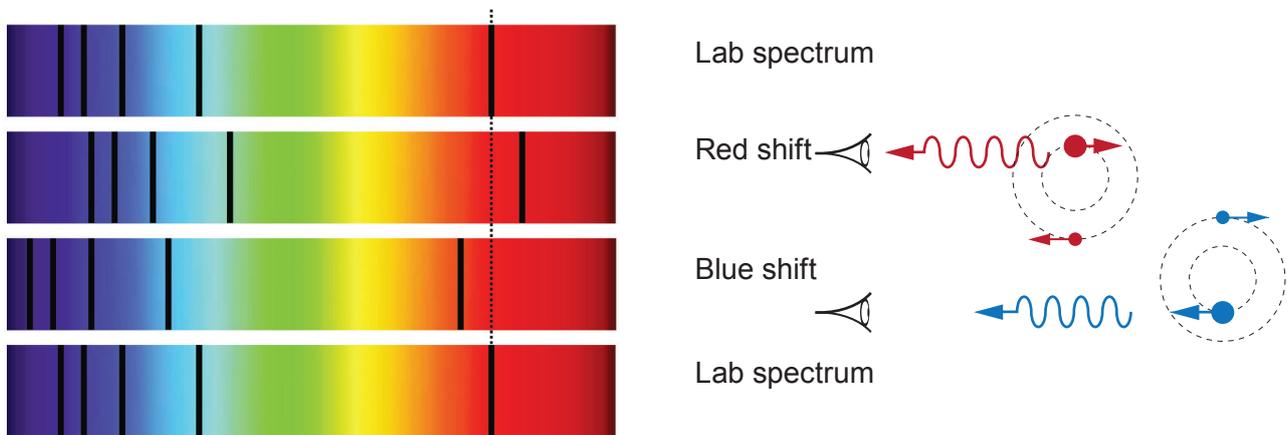
Another important property to understand is stellar mass. Stars can be 'weighed' using the laws of Kepler and Newton. Recall that Newton's modification to Kepler's 3rd law is:

$$(M + m)T^2 = a^3 \quad 16$$

where T is the orbital period (in years), a the semi-major axis of the orbit (in astronomical units), and M and m the masses of the two objects (in solar masses). If we could identify **binary stars** that orbit around each other, and if we could measure their period and their semi-major axis, we could measure their total mass.

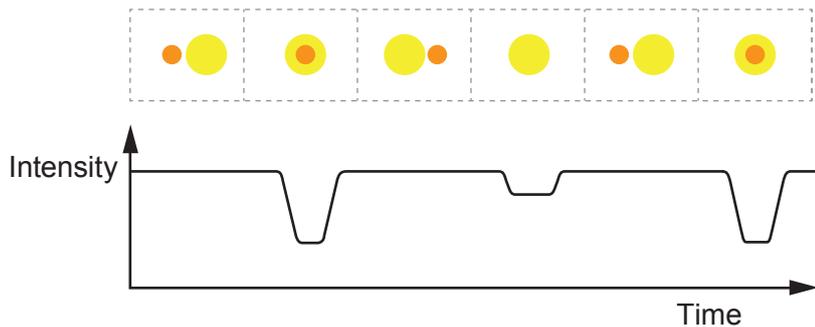
The universe is kind to us. Perhaps $\frac{1}{2}$ of all stars are binary stars. Astronomers have different names for these stars, which depend on how we identify and perceive their binary nature. Here's a list of terminology; note that the same stars can occasionally fall into more than one category. 17

Spectroscopic Binary. This is an extremely important type of binary star. For spectroscopic binaries, the two stars are so close together that an astronomer only sees one object (usually only the brighter of the two stars). However, over time, the astronomer will see that the Doppler shift changes. First, the star will be moving towards us; then away from us; then towards us again. Spectroscopic binaries can have periods of months, days, hours, or even minutes!



Spectroscopic binaries are important because of what they can tell us. First, by monitoring the Doppler shift, one can time how long it takes to complete one forward-backward-forward cycle. That's the star's period. Next, again, from the Doppler shift, one can determine the star's velocity. Velocity times time equals distance, so this gives you the size of the star's orbit, and, with a minimal amount of mathematics, the orbit's semi-major axis. The law of gravity then gives you the total mass of the two stars. 19

If one star is very bright, while the other is very faint, then you will only see the absorption lines of the bright star. In this case, the star is a **single-line spectroscopic binary** and you can't do any more with it. However, if both stars are about equal brightness, then you may see absorption lines from both stars. While one star is moving towards you, the other will be moving away from you. The relative speeds of the stars tell you the relative mass: the more massive star will be moving slowly, while the less massive star will be moving rapidly. In this **double-line spectroscopic binary** case, you can not only measure the total mass of both stars together, but the mass ratio of the stars. You thus have individual masses.

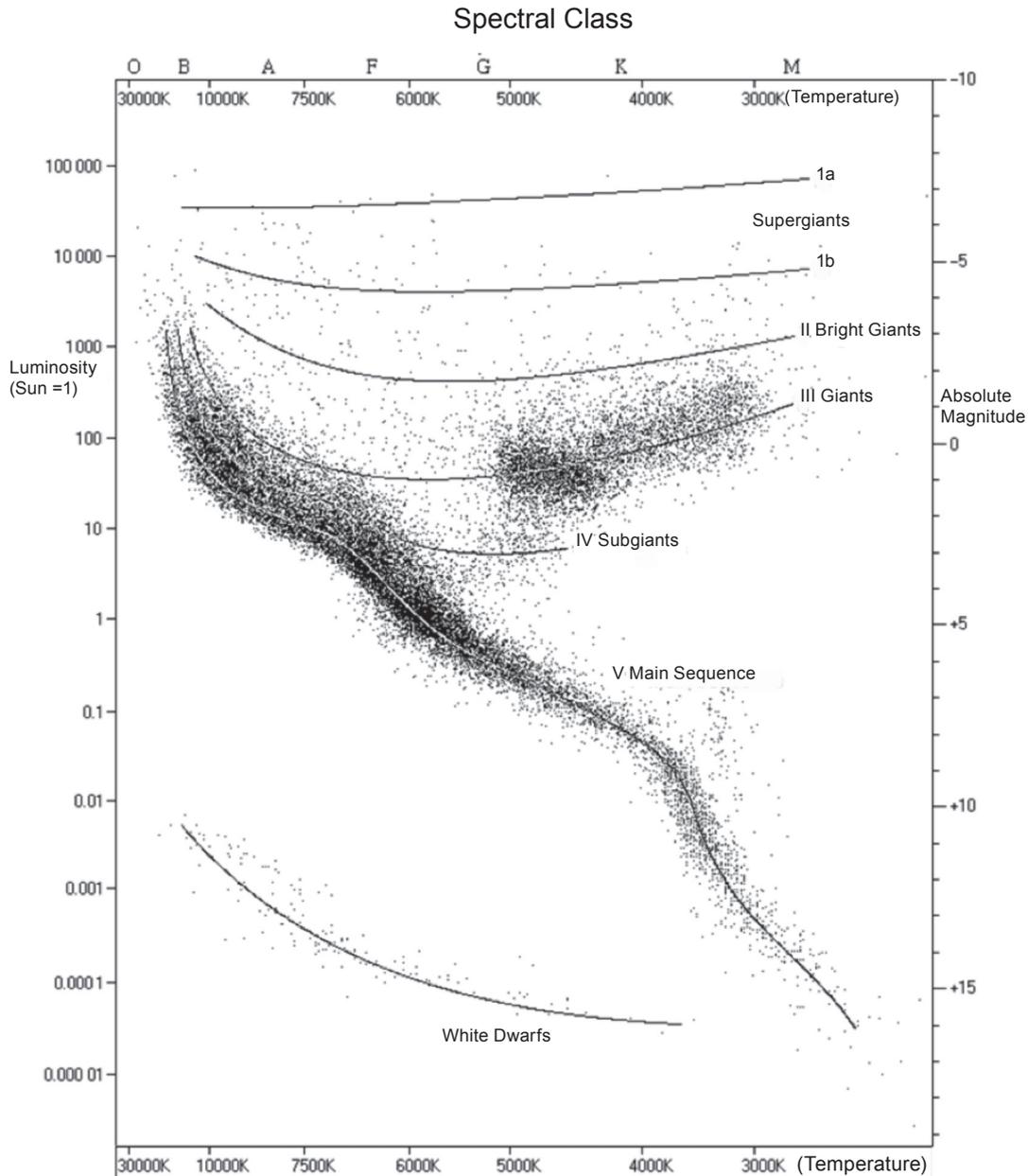


Eclipsing Binary. Eclipsing binaries are like spectroscopic binaries in that the astronomer only sees one object. However, in this case, one star occasionally gets in the way of the other, i.e. one star eclipses the other. When this happens, the light from the system decreases. By following the object's **light curve**, one can measure the star's period. Eclipsing binaries are important because for these stars, you know the orientation; the plane of the orbit is along your line-of-sight.

If you measure the absorption lines of an eclipsing binary, you'll find it to be a spectroscopic binary. Since the inclination of the stars is known, then there is no ambiguity about the mass determination from the Doppler shift. Moreover, by timing how long it takes for the stars to move into and out of eclipse, and by noting how fast the stars are moving, it is possible to use these systems to measure not only a star's mass but also its size.

Incredible though it may seem, each dot on the Hertzsprung-Russell diagram represents a nearby star. All this information on thousands of stars has been gathered using little more than the theories discussed in this article. The equipment used were basic mirrors, prisms (or gratings) and light detectors. However, let it not be forgotten the amount of work required to collate this quantity of data and the intelligence of the few with the insight to develop these theories in the first place.

23



END OF PAPER