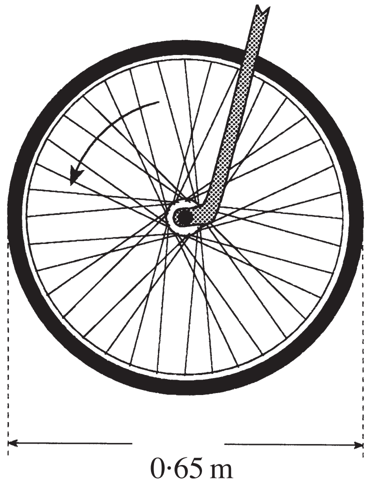
1. A bicycle is supported so that its front wheel does not touch the road. The wheel's **diameter** is 0·65 m. The wheel is spun at a rotation rate of 9·3 revolutions per second.



(a) Show clearly that the *speed* of a point on the outside edge of the wheel is 19 ms^{-1}. [1]

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(b) The *acceleration* of a point on the outside edge of the wheel is much larger than the acceleration due to gravity. Calculate the number of times larger. [3]

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(c) (i) The mass of the wheel is 1·8 kg. Calculate the wheel's *kinetic energy*, assuming that all its mass is concentrated on its outside edge. [2]

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(ii) Explain why the actual kinetic energy will be rather less than this. [1]

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(d) The wheel is brought to rest by applying the brakes. These are pads which rub against the metal rim of the wheel. The mass of the rim is 0·60 kg and the *specific heat capacity* of the metal is 390 Jkg^{-1}K^{-1}. Estimate the rise in temperature of the rim. [3]

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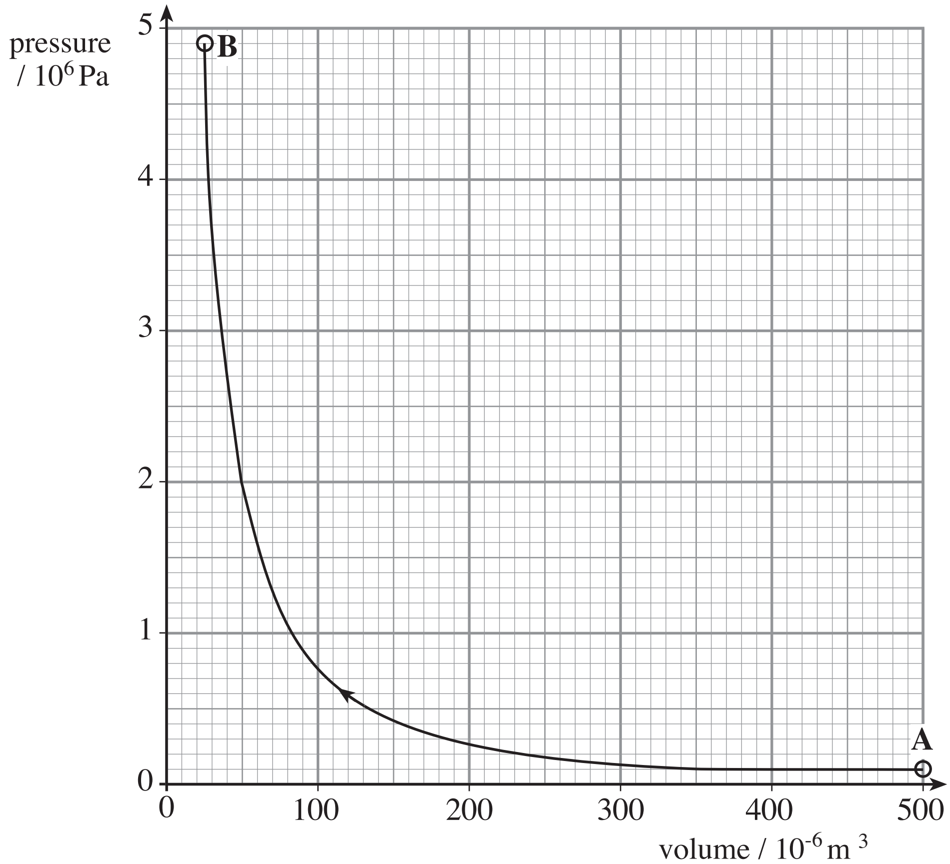
Examiner only

3. One process which takes place in each cylinder of a diesel engine is rapid compression of air by a moving piston. A graph of pressure against volume is given for the process.



(a) Intitially (point **A** on graph) the air is at a temperature of 300 K and a pressure of $0{\cdot}10 \times 10^6$ Pa. It occupies a volume of $500 \times 10^{-6}\,\text{m}^3$.

(i) Calculate the number, *n*, of moles of air in the cyclinder. [2]

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(ii) Calculate the final *temperature* of the air, (its temperature at point **B**). [1]

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(b) The *internal energy* of the air is given by $U = ncT$ in which $c = 20{\cdot}7\ \text{J K}^{-1}\text{mol}^{-1}$ and T is the kelvin temperature. Calculate the increase in internal energy of the air between **A** and **B**. [2]

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Examiner only

(c) The *work* done between **A** and **B** by the piston on the gas is 220 J. State how you could check this figure using the graph. You are not required to perform any calculation. [2]

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(d) Use the *first law of thermodynamics* to calculate the *heat* flow during the compression, stating whether heat flows into or out of the air. Explain your reasoning. [3]

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4. *(a)* The *kinetic theory* gives the pressure of an ideal gas as $pV = \frac{1}{3}Nm\overline{c^2}$.

(i) In terms of symbols selected only from $V, N\, m, \overline{c^2}$, write formulae for

(I) the density, ρ, of the gas, [1]

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(II) the mean (translational) kinetic energy of a molecule. [1]

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(ii) Show, in clear steps that the total (translational) kinetic energy of the gas molecules is equal to $\frac{3}{2}pV$. [2]

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(b) A room measures 3·0 m × 4·0 m × 2·5 m. Treat the air inside it as if it consisted wholly of nitrogen of density 1·2 kg m^{-3}. The pressure is 100 kPa.

(i) Calculate the r.m.s. speed of the molecules. [3]

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(ii) Show clearly which is greater: the total translational kinetic energy of the molecules in the room, or the kinetic energy of a 20 tonne lorry (mass: 20×10^3 kg) travelling at 45 miles per hour (20 m s^{-1}). [3]

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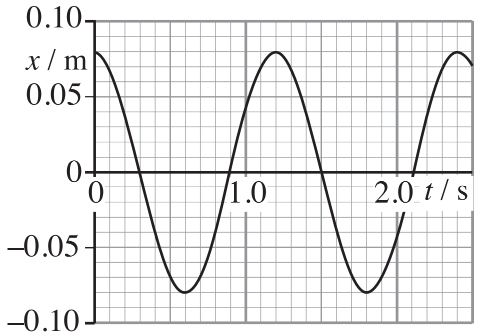
7. In an investigation of *simple harmonic motion*, a trolley is attached to a fixed point by means of a spring which can be compressed or extended with a spring constant, k of 40 Nm^{-1}. The trolley is displaced from its equilibrium position and released at time $t = 0$.

A graph of its displacement, x, against time, t, is drawn with the aid of data-logging equipment.



(a) (i) Write down the value of the *amplitude* of the oscillations. .... [1]

(ii) Write down the value of the *period*. .... [1]

(iii) Show that the mass of the trolley is approximately 1·5 kg. [3]

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(b) The displacement, x, of the trolley is given by $x = A \sin(\omega t + \varepsilon)$ in which $\varepsilon = \frac{\pi}{2}$.

(i) Calculate ω. [2]

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(ii) Showing your working clearly, use the equation to find x when $t = 0{\cdot}40$ s. [2]

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(iii) Comment on whether your previous answer is consistent with the graph. [1]

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(c) Calculate the maximum *speed* of the trolley. [2]

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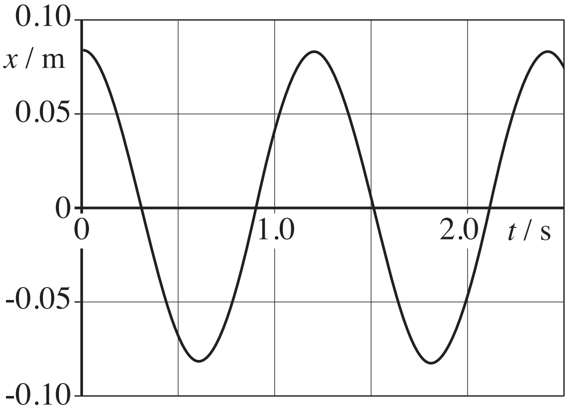
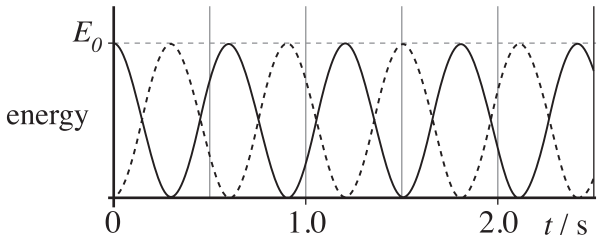
Examiner only

(d)





The x — t graph is shown again, to the left, for ease of reference. Underneath, the system's potential energy and kinetic energy are shown.

(i) State which of these two energies the dotted graph represents, giving your reasoning. [2]

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(ii) Calculate the value of E_0, marked on the energy axis above. [2]

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(iii) Explain how the *principle of conservation of energy* applies to the system. [2]

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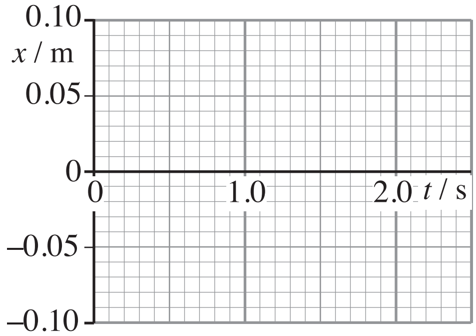
(e)



A large piece of card is now attached to the trolley, so it experiences significant air resistance. The trolley is given the same initial displacement as previously, and released.

Sketch a possible displacement — time graph on the axes provided. Damping is less than critical.

[2]

1. Radon is a naturally occurring radioactive gas that emits α-particles.

(a) Explain briefly which organ(s) of the human body would be at most risk from radon gas. [3]

(b) The half life of radon is $3{\cdot}3 \times 10^5$ s.

(i) How long will it take a sample of radon to decay to 25% of its initial activity? [1]

(ii) How long will it take a sample of radon to decay to 33% of its initial activity? [3]

(c) A beam of radiation of initial intensity I_0 consists of one of α, β or γ radiation. The intensity I of the beam is measured to decrease exponentially with penetration distance x in aluminium according to the equation:

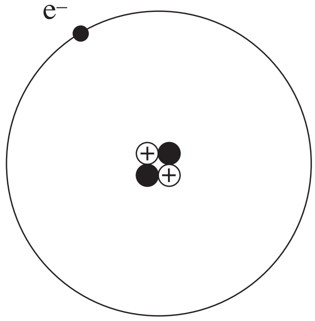
$$I = I_0 e^{-\mu x}$$

(i) The absorption coefficient, μ, for the beam of radiation is $10\,\mathrm{m}^{-1}$. Show that the intensity drops by approximately 3% in 3mm of aluminium. [1]

(ii) Explain briefly which radiation α, β or γ is present in the beam. [2]

Examiner only

5. The diagram is of the helium **ion** He^+ (not to scale).
The radius of the electron orbit is 26 pm.



(a) (i) Calculate the magnitude of the electrostatic force experienced by the electron. [2]

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(ii) Calculate the magnitude of the gravitational force exerted by the nucleus on the electron (the mass of the He nucleus is 4·00u). [2]

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(iii) Comment on the relative magnitudes of these forces. [1]

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(b) Calculate the electrical potential energy of the electron. [2]

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(c) By considering the centripetal force on the electron, calculate its kinetic energy. [3]

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Examiner only

6. The following is a nuclear reaction that occurs inside red giant stars.

$$^{12}_{6}\text{C} + ^{12}_{6}\text{C} \longrightarrow ^{16}_{8}\text{O} + ^{A}_{Z}\text{X} + ^{A}_{Z}\text{X}$$

(a) (i) State the values of *A* and *Z*. $A =$ .... $Z =$ .... [1]

(ii) What is X? [1]

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(b) (i) Calculate the energy released in the above reaction using the data provided below. [4]

mass of $^{12}_{6}C = 11{\cdot}9967\text{u}$, mass of $^{16}_{8}O = 15{\cdot}9905\text{u}$, mass of $X = 4{\cdot}0015\text{u}$, $1\text{u} = 931$ MeV

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(ii) Explain briefly why the data provided is not good enough to give an accurate value for *(b)*(i). [1]

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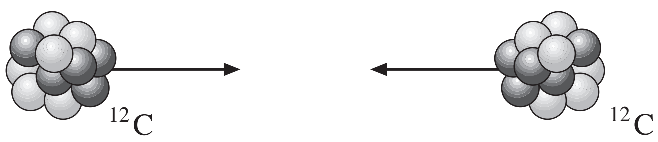
Inside a star, for this reaction to occur, two carbon nuclei must approach each other with high energies and collide head on. The distance of nearest approach must be less than 10·0 fm for this reaction to occur.



(c) (i) Show that the electrical potential energy of the carbon nuclei when they are separated by a distance of 10·0 fm is around 8×10^{-13} J. [2]

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(ii) State the total initial K.E. of the carbon nuclei before the collision. Convert your answer to eV. [2]

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(d) Assume that the carbon nuclei in the star behave like an ideal gas. Estimate the temperature inside the star given that the mean kinetic energy of the nuclei is around 8×10^{-15} J. [3]

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(e) The star has a mass of $5{\cdot}4 \times 10^{31}$ kg and a radius of $1{\cdot}5 \times 10^{11}$ m.

(i) Calculate the speed of a carbon nucleus at the outer edge of the star which has just enough KE to escape the gravitational influence of the star. [4]

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(ii) The **mean** speed of carbon nuclei in the outer atmosphere of the red giant is close to the escape speed. Explain briefly whether this is significant to the star and to the Universe. [2]

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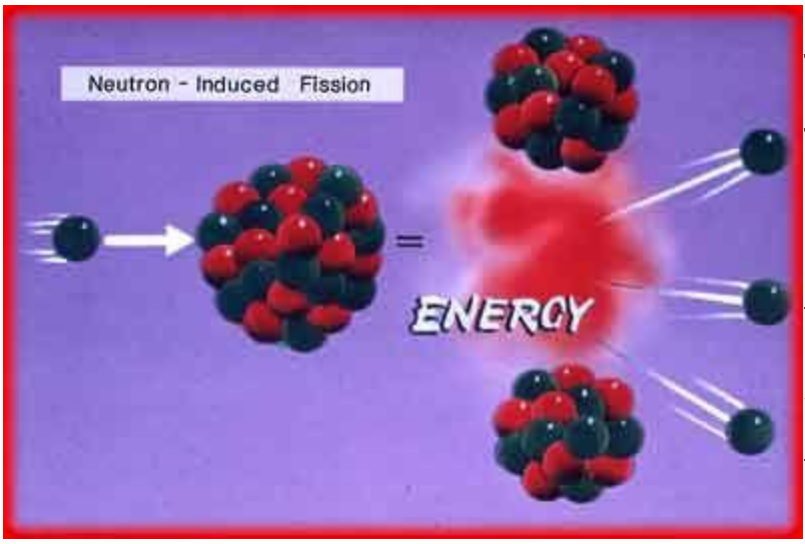
SECTION B

Inside the sun, fusion reactions take place at very high temperatures and enormous gravitational pressures

The foundation of nuclear energy is harnessing the power of atoms. Both fission and fusion are nuclear processes by which atoms are altered to create energy, but what is the difference between the two? Simply put, fission is the division of one atom into two, and fusion is the combination of two lighter atoms into a larger one. They are opposing processes, and therefore very different.

The word fission means "a splitting or breaking up into parts" (Merriam-Webster Online, www.m-w.com). Nuclear fission releases heat energy by splitting atoms. The surprising discovery that it was possible to make a nucleus divide was based on Albert Einstein's prediction that mass could be changed into energy. In 1939, scientist began experiments, and one year later Enrico Fermi built the first nuclear reactor.

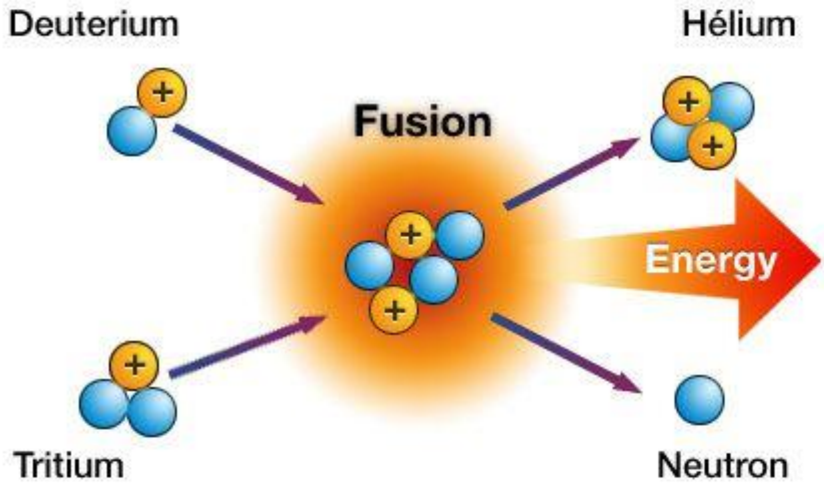


Nuclear fission takes place when a large, somewhat unstable isotope (atoms with the same number of protons but different number of neutrons) is bombarded by high-speed particles, usually neutrons. These neutrons are accelerated and then slammed into the unstable isotope, causing it to fission, or break into smaller particles. During the process, a neutron is accelerated and strikes the target nucleus, which in the majority of nuclear power reactors today is Uranium-235. This splits the target nucleus and breaks it down into two smaller isotopes (the fission products which are Barium-139 with a binding energy per nucleon of 8.5MeV and Kryton-94 with a binding energy per nucleon of 8.7MeV), three high-speed neutrons, and a large amount of energy.

This resulting energy is then used to heat water in nuclear reactors and ultimately produces electricity. The high-speed neutrons that are ejected become projectiles that initiate other fission reactions, or chain reactions.

The word fusion means "a merging of separate elements into a unified whole". Nuclear fusion refers to the "union of atomic nuclei to form heavier nuclei resulting in the release of enormous amounts of energy". Fusion takes place when two low-mass isotopes, typically isotopes of hydrogen, unite under conditions of extreme pressure and temperature.

Fusion is what powers the sun. Atoms of Tritium and Deuterium (isotopes of hydrogen, Hydrogen-3 (binding energy 2.8MeV per nucleon) and Hydrogen-2 (binding energy 1.1MeV per nucleon), respectively) unite under extreme pressure and temperature to produce a neutron and a helium isotope (He-4 with a binding energy per nucleon of 7MeV). Along with this, an enormous amount of energy is released, which is several times the amount produced from fission.



Scientists continue to work on controlling nuclear fusion in an effort to make a fusion reactor to produce electricity. Some scientists believe there are opportunities with such a power source since fusion creates less radioactive material than fission and has a nearly unlimited fuel supply. However, progress is slow due to challenges with understanding how to control the reaction in a contained space.

Both fission and fusion are nuclear reactions that produce energy, but the applications are not the same. Fission is the splitting of a heavy, unstable nucleus into two lighter nuclei, and fusion is the process where two light nuclei combine together releasing vast amounts of energy. Fission is used in nuclear power reactors since it can be controlled, while fusion is not utilized to produce power since the reaction is not easily controlled and is expensive to create the needed conditions for a fusion reaction. Research continues into ways to better harness the power of fusion, but research is in experimental stages. While different, the two processes have an important role in the past, present and future of energy creation.

Question – use your knowledge of the binding energy vs nucleon number to compare the difference in the energy given off, **per reaction** (fusion vs fission). Perform some calculations to find the energy released when hydrogen isotopes fuse to form helium, then do the same for the fission of uranium. Explain your workings and do not rely entirely on calculations for your answer. [10 MARKS]