Physics A

Unit: G484: The Newtonian World

1(a) State Newton's second law of motion. **[2]**	
Candidate style answer	*Examiners commentary*
The resultant force on an object is proportional to the rate of change of momentum of the object	In part (a) the candidate gains the first mark. However the detail, i.e. *the momentum change takes place in the direction of the force*, is omitted so the second mark is not awarded.

(b) Explain how the principle of conservation of momentum is a natural consequence of Newton's laws of motion. **[3]**	
Candidate style answer	*Examiners commentary*
Newton's third law states that in a collision the forces acting on the two objects are equal but opposite. The collision time is the same for both so the impulses on the objects are equal and opposite. Impulse = change in momentum so there is no change in momentum	Part (b) is explained clearly to earn all three marks.

(c) Most cars are now fitted with safety airbags. During a sudden impact, a triggering mechanism fires an ammunition cartridge that rapidly releases nitrogen gas into the airbag. **In a particular simulated accident, a car of mass 800 kg is travelling towards a wall. Just before impact, the speed of the car is 32 m s^{-1}. It rebounds at two-thirds of its initial speed. The car takes 0.50 s to come to rest. During the crash, the car's airbag fills up to a maximum volume of 3.4×10^{-2} m^3 at a pressure of 1.0×10^5 Pa. The temperature inside the airbag is 20 ^{0}C. Calculate:** **(i) the change in the momentum of the car** **[2]**	
Candidate style answer	*Examiners commentary*
the rebound speed = 2/3 × 32 = 21.3 change in momentum = 800 (32 + 21.3) = 800 x 53.3 = 4.26×10^4 kg m s^{-1} momentum change = 4.26×10^4 kg m s^{-1}.	In part (c) (i) the candidate continues to show an understanding of the vector nature of momentum, gaining full marks for this.

(ii) the magnitude and direction of the average force acting on the car during impact. [3]	
Candidate style answer	*Examiners commentary*
average force = $4.26 \times 10^4 / 0.50 = 8.52 \times 10^4$ force = . 8.5×10^4. N direction ….opposite to the initial direction.	part (c)(ii). gaining full marks for this

(iii) the mass of nitrogen inside the cartridge. molar mass of nitrogen = 0.014 kg mol^{-1} [3] [Total: 13]	
Candidate style answer	*Examiners commentary*
$pV = NkT$ so $N = pV / kT$ $N = (1.0\times10^5 \times 3.4\times10^{-2}) / (1.38\times10^{-23} \times 293) = 8.4 \times 10^{23}$ mass of nitrogen $= 8.4 \times10^{23} / 6.02\times10^{23}$) $\times 0.014 = 0.0196$ mass = 0.020. kg	Part (c) (iii) is also answered clearly and fully.

Comments: The candidate scores 12/13 on this first question which is a high score suggesting that this may be a high grade candidate. There are several testing points in this question and all have been correctly negotiated.

2(a) Define *gravitational field strength* at a point in a gravitational field. [1]	
Candidate style answer	*Examiners commentary*
Gravitational field strength at a point is the force per unit mass at that point	Full marks are scored for the clear and full answers to all parts

(b) A satellite of mass 1500 kg is launched from the surface of the Earth into a circular orbit around the Earth at a height of 6800 km above the Earth's surface. At this height the satellite has an orbital period of 8.5×10^3 s. The radius of the Earth is 6400 km. (i) A student uses the equation. gain in potential energy = mgh to determine the increase in the potential energy of the satellite. Suggest why this equation cannot be used and state whether the student's answer would be less than, equal to, or greater than the actual value. [2]	
Candidate style answer	*Examiners commentary*
The gravitational field strength g varies as 1/r2 where r is the distance from the	Full marks are scored for the clear and full answers to all parts

centre of the Earth so g is not constant. *The value will be too big because g becomes less than 9.8 m s-2*	

(ii) Calculate the kinetic energy of the satellite. **[3]**	
Candidate style answer	*Examiners commentary*
the speed of the satellite = 2πr /T $v = 2\times\pi \times (6800 + 6400) \times 10^3 / 8.5\times10^3 = 9.76 \times 10^3$ *so* $KE = ½mv^2 = 1/2\times1500\times(9.76\times10^3)^2 = 7.14 \times 10^{10}$ *kinetic energy =* $. 7.1 \times 10^{10}.$ *J*	Full marks are scored for the clear and full answers to all parts

(ii) State a benefit of having a satellite in a geostationary orbit round the Earth. Explain whether or not a satellite orbiting at a height of 6800 km above the Earth's surface is in a geostationary orbit. ✎ ***In your answer, you should use appropriate technical terms, spelled correctly.*** **[3]**	
Candidate style answer	*Examiners commentary*
A satellite in geostationary orbit stays above the same point on the Earth at all times so that a television dish on a house can be fixed in position. The dish does not need to track the satellite. *The period of the satellite is* 8.5×10^3 *s which is about 1/10 of a day so it is travelling much too fast.*	In (b) (iii) the technical term required is not used so the allocated mark is not awarded.

(ii) q Fig. 2.1 shows how the gravitational field strength g varies with distance r from the centre of a planet of radius 2.0 × 107 m

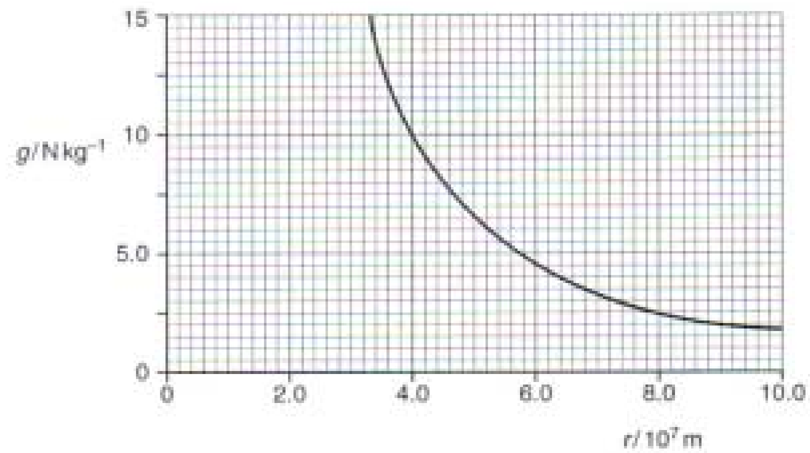

Fig. 2.1

The gravitational field strength on the surface of the planet is 40 N kg^{-1}.

(i) Use Fig. 2.1 to write down the value for *g* at a height of 4.0×10^7 m above the <u>surface</u> of the planet.

[2]

Candidate style answer	*Examiners commentary*
At a height of 4.0 × 107 m the value of r on the graph is 6.0 × 107 m where g = 4.5 *g = . 4.5.N kg-1*	

(ii) Calculate the mass *M* of the planet. Assume that the planet can be treated as a point mass of magnitude *M* situated at its centre.

[2]

Candidate style answer	*Examiners commentary*
using g = GM/r2 M = gr2/G *so M = 40×4.0×1014 / 6.67 ×10–11 = 2.4 × 1026 kg* *M =. 2.4 × 1026. kg*	

(iii) Astronomers investigating the planet believe that the planet's interior has a uniform density. Show that within the interior of the planet, its gravitational field strength *g* is proportional to the distance *r* from the centre.

[2]
[Total: 15]

Candidate style answer	*Examiners commentary*
M = pV	In (c) (iii) the candidate is obviously at a loss as to how to proceed and presumably did not have time at the end of the paper to return to complete the question. The definition of density is not enough to be awarded a mark.

Comments: The candidate shows good knowledge of the topic gravitation. The total for the question is 12/15

3(a) Define *simple harmonic motion*.

✏ **In your answer, you should use appropriate technical terms, spelled correctly.**

[2]

Candidate style answer	*Examiners commentary*
The acceleration of the trolley is proportional to its displacement from equilibrium. The acceleration is always directed towards the equilibrium position.	Part (a) gains both marks for the full definition and the correct spelling of displacement.

(ii) **Fig. 3.1 shows a trolley attached to the end of a helical spring. The trolley executes simple harmonic motion on the smooth table.**

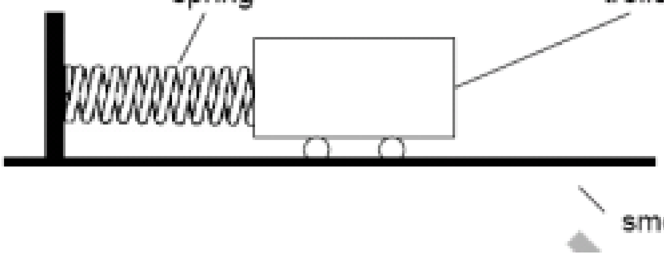

Fig. 3.1

(i) Describe how, for this oscillating trolley, you can determine the following quantities using a stopwatch and a ruler.

1 the frequency oscillation

[2]

Candidate style answer	Examiners commentary
The frequency equals 1/period so I would use the stopwatch to measure the period. To do this time 10 or 20 oscillations and then divide the time by the number of oscillations	Part (b) (i) is explained well and easily gains all four marks.

2 the maximum speed of the trolley

[2]

Candidate style answer	Examiners commentary
The maximum speed is given by the formula: $v_{max} = (2\pi f) A$. I would measure the amplitude using the ruler and substitute it and the frequency I have already measured into the formula	

(ii) The amplitude of the trolley is doubled. The trolley still moves in simple harmonic motion. State with a reason the change, if any, in the maximum speed of the trolley.

[2]

Candidate style answer	Examiners commentary
The maximum speed is given by the formula: $v_{max} = (2\pi f)A$. As the trolley still moves in SHM, the maximum speed is doubled	In part (b) (ii) the candidate has not stated clearly that SHM is an isochronous motion so fails to gain the second mark.

(iii) Using your knowledge of Hooke's law and Newton's second law, determine the period *T* of the trolley in terms of the force constant *k* of the spring and the mass *m* of the trolley.

[2]

[Total: 10]

Candidate style answer	Examiners commentary
For a spring $F = kx$ and the mass will	In part (b) (iii) the examiner senses that the candidate has done this sort of analysis

have an acceleration of F/m *So* $a = kx/m$. *For SHM,* $a = (2\pi f)\ 2x$ *giving* $(2\pi f)\ 2 = k/m$. *and thus* $T = 2\pi \sqrt{(m/k)}$.	several times before and is familiar with what is required. There is some glossing over of minus signs but the answer is well worth both marks.

Comments: The candidate either knows the subject well and/or has used the *formulae and relationships* sheet to full effect. The total for this question is 9/10.

4(a) (i) Explain the term *internal energy*.

[2]

Candidate style answer	*Examiners commentary*
The internal energy of a body is the sum of the kinetic and potential energies of all the atoms of the body.	In part (a) (i) there is no mention that the kinetic energy of the atoms is *random* or that the atoms *are moving randomly* so the second mark is not awarded.

(ii) Define *specific heat capacity of a substance*.

[1]

Candidate style answer	*Examiners commentary*
The specific heat capacity of a substance is the energy required per unit mass to increase the temperature by 1 K	

(b) Consider a 2.0 kg block of aluminium. Assume that the heat capacity of aluminium is independent of temperature and that the internal energy is zero at absolute zero. Also assume that the volume of the block does not change over the range of temperature from 0 K to 293 K. The specific heat capacity of aluminium is 920 J kg^{-1} K^{-1}.

(i) Show that the internal energy of this block at 20 ^{o}C is 540 kJ.

[2]

Candidate style answer	*Examiners commentary*
Using $E = mc\Delta\theta$ $E = 2.0 \times 920 \times 293 = 5.39\times105 \approx 540$ *kJ*	

(ii) Hence show that the mean internal kinetic energy per atom in the 2.0 kg aluminium block at 20 ^{o}C is about 1.2 × 10^{-20} J.

molar mass of aluminium is 0.027 kg mol^{-1}.

[3]

Candidate style answer	*Examiners commentary*
the block contains 74.1 moles of atoms so the number of atoms is $74.1 \times 6.02 \times 10^{23} = 4.46 \times 10^{25}$ *and the mean energy per atom* $= 5.39 \times 10^{5}/4.46 \times 10^{25} = 1.2 \times 10^{-20}$ *J*	In part (b) (ii) the calculations have been completed to three significant figures and then in the last line there are only two. The examiners' rule is that in *show that* questions the candidate must indicate somehow that the calculations have been completed to the very end. Rather harshly but for consistency this rule is followed here so the candidate fails to gain the final mark.

(iii) In 1819, Dulong and Petit measured the specific heat capacities of bodies made from different substances and found that for one mole of each substance, the molar heat capacity was about 25 J mol^{-1} K^{-1}. Use the data from either (i) or (ii) to show that this is true for aluminium. [2]	
Candidate style answer	*Examiners commentary*
540 kJ is the energy of 74.1 moles of aluminium so the energy per mol is 7.3 kJ mol^{-1}	In part (b) (iii) the calculation is left incomplete. For some reason the candidate has not realised that all that has to be done is to divide the number that has been reached by the temperature, namely 293 to achieve the required answer. The mark scheme requires this division for the first mark so the candidate scores zero.

(c) A student performs an experiment to measure the specific heat capacity of a 1 kg aluminium block using the apparatus shown in Fig 4.1.

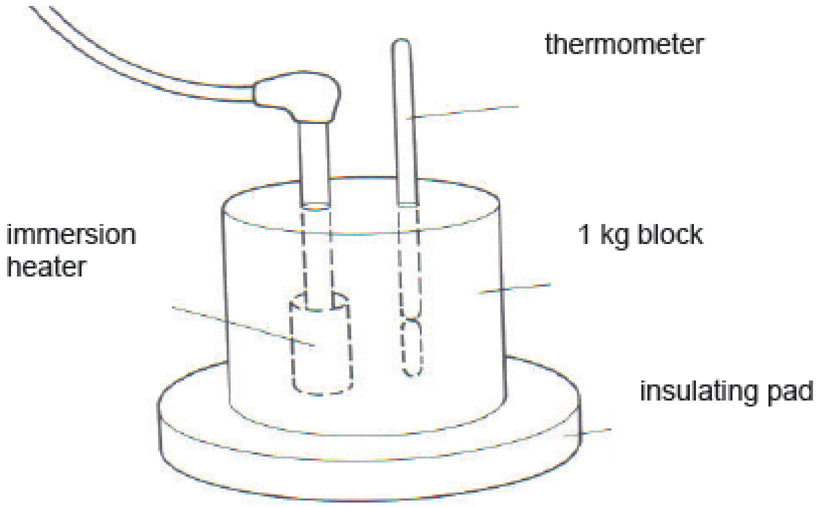

Fig 4.1

He heats the block using a 50 W electrical heater. Using the value for aluminium from a data book, he predicts the time to heat the block from 20 °C to 30 °C, to be 3.1 minutes. He heats the block for this time but finds that the temperature of the block continues to rise after he switches the heater off. He also finds that the highest temperature reached is only 9.1 °C.

Explain his observations and why he does not obtain the data book value of 920 J kg^{-1} K^{-1}.

[4]

[Total: 14]

Candidate style answer	*Examiners commentary*
Heat energy from the heater is still passing through the block when the heater is switched off as the block is hotter at the heater than at the thermometer. Some of the energy escapes from the surfaces of the block to the surroundings so its temperature cannot rise by 10 K.	In part (c) the answer is essentially complete but the candidate surprisingly has not used any of the thermal energy transfer words, e.g. conduction in the metal and convection and radiation from the surface. Thus the mark awarded is only three.

Comments: The candidate scores 9/14 for this question.

5(a) State any two assumptions of the kinetic theory of gases. **[2]**	
Candidate style answer	*Examiners commentary*
The atoms are in constant random motion continually making elastic collisions mixing up their energies.	Part (a) gains both marks.

(b) The atoms on the surface of a hot star may be treated as an ideal gas. Ideal gases obey the kinetic theory of gases. The interior of a particular star has a core temperature of 10^9 K and its surface temperature is 4000 K. For the hydrogen atoms of this star, calculate the ratio: $$\text{ratio} = \frac{\text{average speed of atoms in the core}}{\text{average speed of atoms on the surface}}$$ **[2]**	
Candidate style answer	*Examiners commentary*
the average speed is proportional to the temperature *so the ratio = $10^9/4000 = 2.5 \times 10^5$* *ratio = ... 2.5×10^5..*	Part (b) forfeits both marks as v^2 is proportional to absolute temperature

(c) Suggest why the hydrogen atoms on the surface of the star do not all have the same speed. **[1]**	
Candidate style answer	*Examiners commentary*
The atoms are in constant random motion continually making elastic collisions mixing up their energies so they have different speeds.	Part (c) is a repeat of part (a) but is the answer to the question so gains the mark.

(d) The emission spectrum of hydrogen gas atoms shows a strong red light of wavelength 656.3 nm. The motion of the atoms on the surface of the star in (b) causes *spectral broadening* of this line due to an effect known as the Doppler effect. The wavelength of light become longer when the hydrogen atoms on the surface of the star are moving away from our line of sight and shorter when they are moving towards us. This wavelength λ of the spectral line is broadened by an amount Δλ. Astronomers use the equation below to determine the surface temperature *T* in kelvins (K) of a star: $$\frac{\Delta\lambda}{\lambda} = \sqrt{\frac{2kT}{mc^2}}$$ **where *k* is the Boltzmann factor, *m* is the mass of the hydrogen atom and *c* is the speed of light in a vacuum.** **(i) Calculate the spectral broadening Δλ for the 656.3 nm line emitted from the star in <u>(b)</u>.** **[2]**	
Candidate style answer	*Examiners commentary*
Δλ = 656.3×√(2×1.38×10–23 × 4000 / 1.67 ×10–27 ×9.0×1016)	The substitution of figures into the formula in part (d) (i) is completed successfully so is

$\Delta\lambda$ = 1.778 × 10-2 *$\Delta\lambda$ = .1.778 × 10-2. nm*	awarded both marks.

(ii) Suggest why the spectral lines from heavier atoms, such as carbon, show very little broadening. **[8]** **Paper Total [60]**	
Candidate style answer	*Examiners commentary*
	Either the candidate ran out of time or did not know what to answer for (ii).

Comments: The candidate is awarded 5/8 marks for this question. The total score for the paper is 47/60 which is 78%; almost certainly a top grade. The candidate has shown a commanding knowledge of the topics covered on this paper. Marks have been lost in most cases through lack of examination technique or lack of detail rather than for fundamental errors in understanding of the topics.