Physics

Question	Maximum Mark	Mark Awarded
#1	15	
#2	9	
#3	14	
#4	20	
#5	11	
#6	13	
#7	6	
Total	88	

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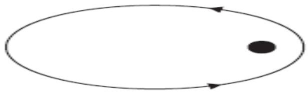
#1

(a) The diagram shows the elliptical orbit of a planet around a star. Use the diagram (by adding to it) to explain Kepler's second law of planetary motion. [2]



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(b) Starting with Newton's law of gravitation, show that for a circular orbit, the period of orbit, T, of a planet around a star is related to its distance, r, from the centre of the star by the relationship $T^2 \propto r^3$. [Assume the mass of the planet is much less than the mass of the star.] [3]

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(c) Mars has two small moons, Phobos and Deimos. The diagram shows their orbital paths around Mars.

(i) Phobos has an orbital period of 7.7 hours and the radius of its orbit is 9400 km. Show that the mass of Mars is approximately 6.4×10^{23} kg. [3]

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(ii) It is proposed to send a space-probe to study Phobos and Deimos. The first part of the mission will be to place the probe in orbit around Phobos.

I. Show that the gravitational potential due to Mars at the Phobos orbit is approximately $-4.5\ \text{MJ kg}^{-1}$. [2]

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II. The second part of the mission involves manoeuvring the space-probe into a higher orbit to enable it to study Deimos. However, on the journey to Mars the probe used more fuel than was expected. Scientists are now unsure as to whether or not the probe has enough fuel to enable it to reach the orbit of Deimos. The following information is available:

Energy available per kg of space-probe: $4.4\ \text{MJ kg}^{-1}$
Efficiency of fuel-burn process: 60 %
Distance of Deimos from centre of Mars: 23 500 km

Assuming the mass of the fuel is very small compared to the mass of the probe itself, and ignoring the gravitational effects of both moons, determine whether or not the scientists should attempt the manoeuvre. [4]

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(iii) Explain why it is not possible to use the equation $\Delta E_p = mg\Delta h$ when determining the change in the gravitational potential energy of the probe as it moves between these orbits. [1]

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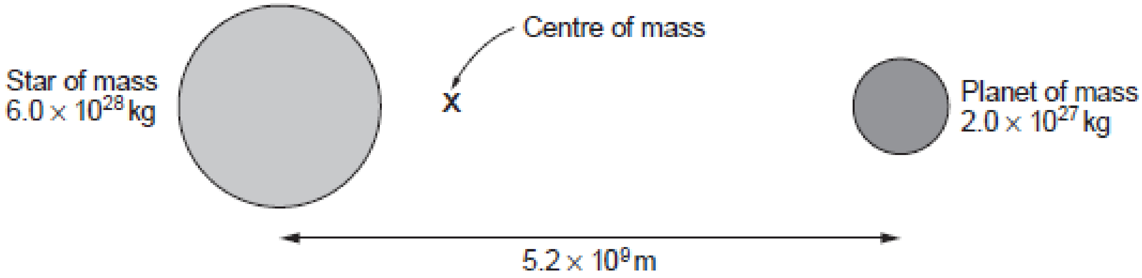
Question taken from Eduqas examination paper 842102, November 2020

#2

7. A star and a planet orbit their mutual centre of mass as shown. The diagram is not to scale.

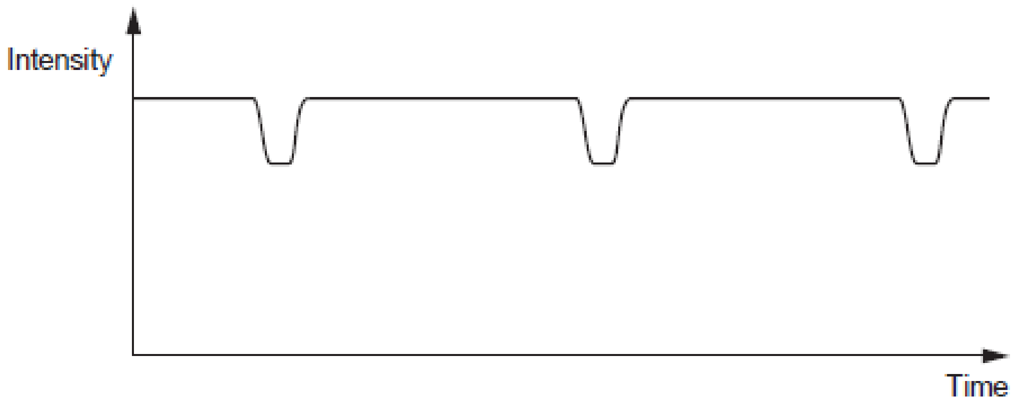


(a) (i) Calculate the period of orbit. [2]

(ii) Calculate the distance of the centre of mass from the centre of the star. [2]

(b) The centre of mass of this star-planet system is at rest relative to the Earth and the system is viewed 'edge-on'. When analysing light of wavelength 656.3 nm from the star, astronomers measure a maximum red shift of 2.0 pm. Determine whether this shift is (approximately) consistent with your answers to *(a)*(i) and (ii). [4]

(c) Astronomers note a periodic dip in the brightness of the star as shown in the sketch graph.



Explain this observation. [1]

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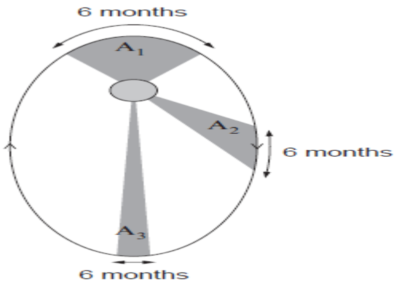
Question taken from Eduqas examination paper 842102, June 2019

#3

Johannes Kepler devoted much of his life to the study of planetary motion. In the process he discovered three laws which describe the motion of any orbital body.

(a) The diagram is taken from a physics text book. Describe how it is used to explain Kepler's 2nd law. [3]



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(b) Use a formula for centripetal acceleration and Newton's law of gravitation to show that, for a planet in circular orbit of radius, r, around a star of mass, M:

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

where T is the period of the planet's orbit. [3]

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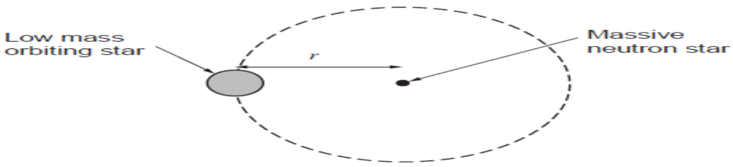
(c) A binary star system consists of a star of low mass orbiting a far more massive neutron star in a circular orbit of radius, r.



(i) When analysing light from the low mass star, a hydrogen line at $\lambda = 486.140$ nm has a maximum Doppler shift of 0.052 nm. Further experimental measurements show that the orbital period is 1.45 years. Show that the radius of the low mass star's orbit is approximately 2.3×10^{11} m. [4]

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(ii) Astronomers believe that the mass of the neutron star is 1.8 times the mass of the Sun. Determine whether or not this is correct, stating any assumption you make. [Mass of Sun = 2.0×10^{30} kg] [4]

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Question taken from Eduqas examination paper 842102, June 2017

#4

ROCKET PHYSICS

(including extracts from REAL WORLD PHYSICS PROBLEMS)

Picture of Saturn V Launch for Apollo 15 Mission. Source: NASA

Rocket physics, in the most basic sense, involves the application of Newton's laws to a system with variable mass. A rocket has variable mass because its mass decreases over time, as a result of its fuel (propellant) burning off. 1

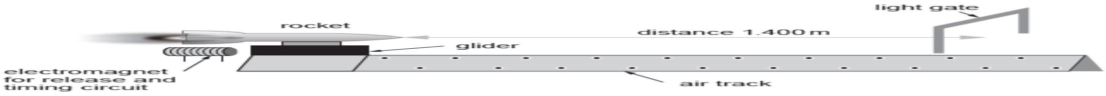
A rocket obtains thrust by the principle of action and reaction (Newton's 3rd law). As the rocket propellant ignites, it experiences a very large acceleration and exits the back of the rocket (as exhaust) at a very high velocity. This backwards acceleration of the exhaust exerts a "push" force on the rocket in the opposite direction, causing the rocket to accelerate forward. This is the essential principle behind the physics of rockets, and how rockets work. 2

Rockets tend to burn fuel at a steady rate and with a constant exhaust speed which produces a constant thrust. However, rocket science is a little more complicated than normal A level physics motion because this does not lead to a constant acceleration. This is due to the decreasing mass of a rocket as it burns its fuel (as stated previously). The usual equation of motion for a rocket is: 3

$$ma = u\frac{\Delta m}{\Delta t} \qquad \textbf{Equation 1}$$

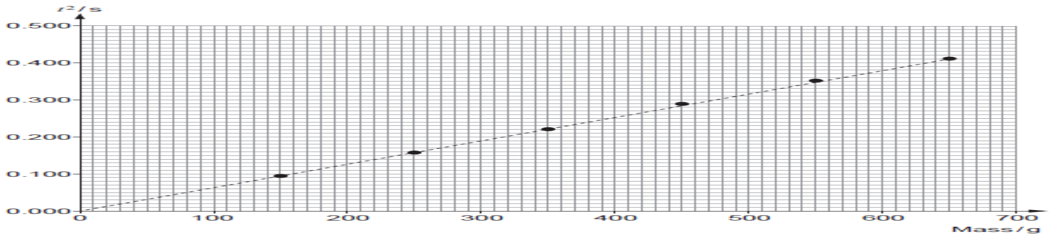
where m is the instantaneous mass of the rocket, a its acceleration, u the velocity of the exhaust gases relative to the rocket and $\frac{\Delta m}{\Delta t}$ the rate at which the mass of the rocket is decreasing. This is a simple application of Newton's 2nd and 3rd laws of motion. 4

If the mass of the rocket is much greater than that of the rocket fuel, we can assume that the acceleration is constant. We can also burn the fuel slowly and then the acceleration will be nice and small so that we can carry out an experiment on an air track to check **Equation 1**. 5



In the set-up opposite, the rocket is attached to a glider and released from rest using the electromagnet. The timer is started automatically and the time is then recorded for the rocket to travel the 1.400 m to the light gate. This process is repeated for a series of glider masses. 6

Mass of glider and rocket / g	Time / s	Corrected time, t / s	t^2 / s
150	0.328	0.308	0.095
250	0.418	0.398	0.158
350	0.490	0.470	0.221
450	0.558	0.538	0.289
550	0.614	0.594	0.353
650	0.663	0.643	0.413



The graph shows a constant acceleration, in excellent agreement with theory. Moreover, the rate of mass loss for the rocket was measured as $1.10 \times 10^{-2}\,\text{kg s}^{-1}$. The exhaust gas speed was $402\,\text{m s}^{-1}$ as measured using the Doppler shift of light emitted by the exhaust gases. These measurements provide a theoretical value of around 4.4 N for the rocket thrust and this is in excellent agreement with the graph too. 7

Answer the following questions in your own words. Direct quotes from the original article will not be awarded marks.

(a) Explain how Equation 1 is an application of Newton's 2nd and 3rd laws of motion (see paragraphs 2 and 4). [3]

(b) The author states in paragraph 5 that the acceleration is "constant" and "nice and small". Explain why this is true (see paragraphs 3 and 5). [3]

(c) (i) The author has made a mistake in the table and the graph with one of the units. Identify the mistake. [1]

(ii) Explain how the corrected time, t, was obtained from the time in the table and suggest why this correction was necessary. [2]

(d) Use equations of uniformly accelerated motion to explain why a graph of t^2 against mass was plotted **and** why the gradient of this graph is expected to be $\frac{2.80}{F}$ (where F is the resultant force in newtons acting on the glider and rocket). [3]

(e) Show that a rate of mass loss of $1.10 \times 10^{-2}\,\text{kg s}^{-1}$ and an exhaust gas speed of $402\,\text{m s}^{-1}$ produce a thrust of approximately 4.4 N (see paragraph 7). [1]

(f) The gradient of the graph is 0.635 in the correct SI unit. Use this to determine whether the force of 4.4 N to which the author refers is consistent with the graph (see paragraph 7 and the graph). [2]

(g) (i) State what is meant by Doppler shift (see paragraph 7). [2]

(ii) Describe how the exhaust gas speed might be measured "using the Doppler shift of light emitted by the exhaust gases" (see paragraph 7). [3]

Question taken from Eduqas examination paper 842101, November 2020

#5

(a) Calculate the critical density of the universe giving appropriate units. [2]

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(b) An astronomer makes the following statement:

Assuming that the rate of expansion of the universe is constant, two objects a distance R apart in space will increase their separation by nearly 15% over a 2 billion year period.
[1 billion = 1×10^9 years]
Justify this statement. [3]

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(c) A star in a distant galaxy shows a bright hydrogen emission line at 475 nm. The equivalent emission line on Earth has a wavelength of 410 nm.

(i) Calculate the radial velocity of the star. [2]

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(ii) Calculate the distance of the star from the Earth. [2]

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(iii) The temperature of the photosphere of the star is 7 100 K. Calculate the mean kinetic energy of particles in the photosphere. Give your answer in eV. [2]

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Question taken from Eduqas examination paper 842102, November 2020

#6

4. *(a)* (i) Use the Principle of Conservation of Energy to show that the critical density, ρ_c, of the universe is given by: [4]

$$\rho_c = \frac{3H_0^2}{8\pi G}$$

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(ii) Use the above equation to show that the critical density of the universe corresponds to approximately 5 atoms of hydrogen per m^3. [2]

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(b) Astronomers analysing the wavelengths of the dark lines from the line spectrum of a distant galaxy note that they are increased by 16 % compared with their normal wavelengths.

(i) State why there is an increase in wavelength. [1]

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(ii) Calculate the distance of the galaxy from Earth. [3]

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(c) Stating an assumption, estimate the age of the universe in years. [3]

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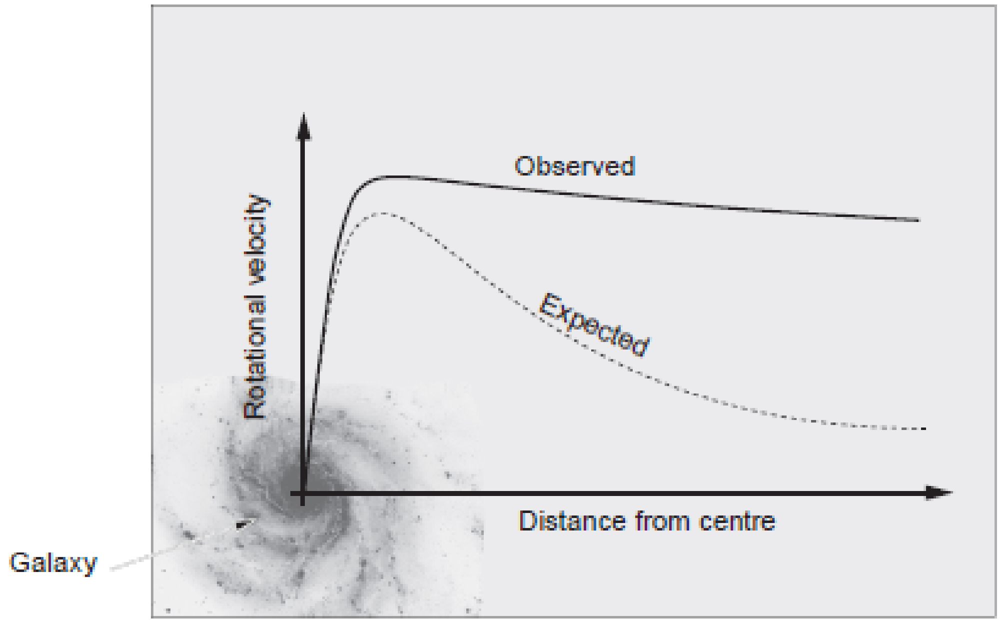
Question taken from Eduqas examination paper 842102, June 2018

#7

5. The diagram shows the key features of the rotation curves for a distant spiral galaxy. Explain how these features relate to the structure and motion of the galaxy. [6 QER]



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Question taken from Eduqas examination paper 842102, June 2018