GCE PHYSICS

S21-A420QS

Assessment Resource number 9

Comprehension Resource I

1 Read through the following article carefully.

ROCKET PHYSICS

Paragraph

(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

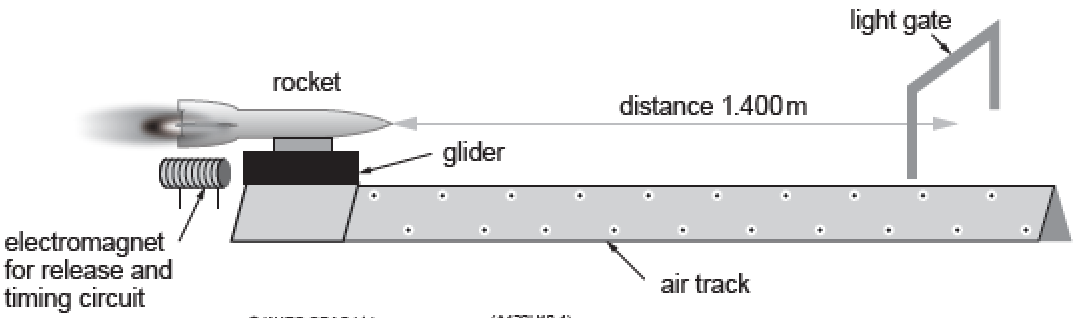
A rocket obtains thrust by the principle of action and reaction (Newton's 3rd law). As the rocket propellant ignites, it experiences a very large acceleration and exits the back of the rocket (as exhaust) at a very high velocity. This backwards acceleration of the exhaust exerts a "push" force on the 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

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

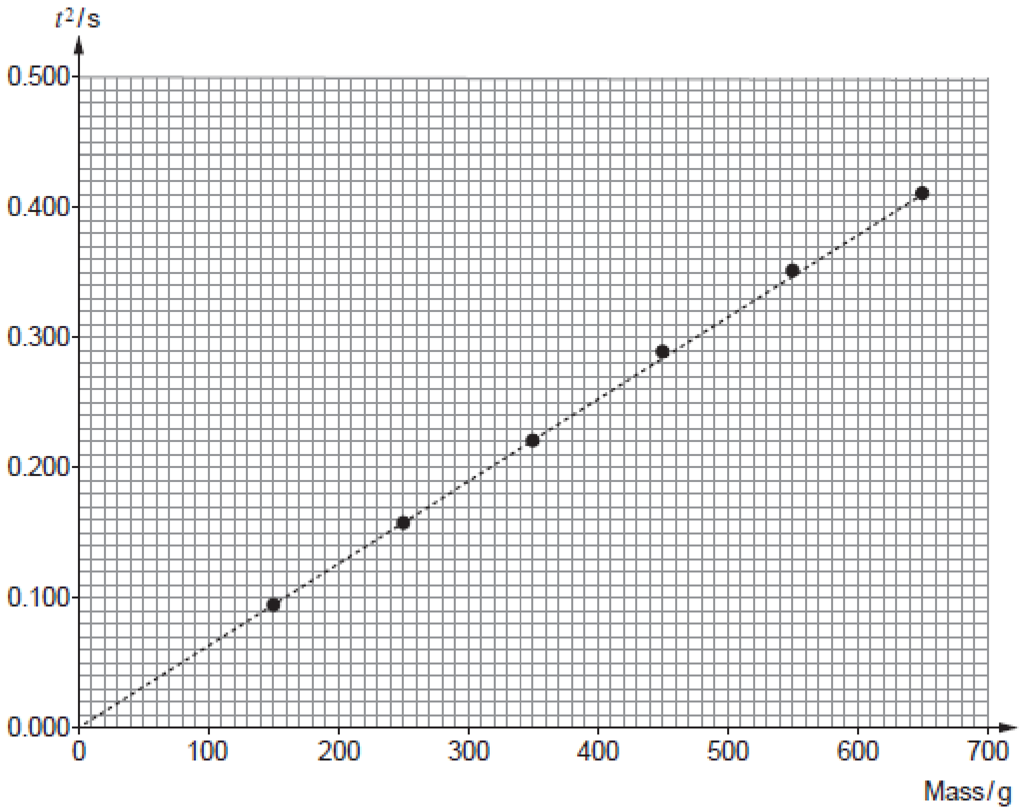
where m is the instantaneous mass of the rocket, a its acceleration, u the velocity of the exhaust gases relative to the rocket and $\frac{\Delta m}{\Delta t}$ the rate at which the mass of the rocket is decreasing. This is a simple application of Newton's 2nd and 3rd laws of motion. 4

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 6
rocket to travel the 1.400 m to the light gate. This process is repeated for a series of glider masses.

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 1.10×10^{-2} kg s^{-1}. The exhaust gas speed was 402 m s^{-1} as measured using the Doppler shift of light emitted by the exhaust 7
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.

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]

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(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]

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

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

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(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]

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

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(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]

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

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(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]

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