7 Space rockets require thrust forces to change their motion in space. The thrust is exerted on the rocket by the fast moving exhaust gases that are ejected downwards.

(a) State *Newton's second law of motion*.

....

....

.... [2]

(b) The mass of a rocket decreases as fuel is used up. The thrust F on a rocket of instantaneous mass m is given by the expression

$$F = V\frac{dm}{dt}$$

where V is the steady velocity of the exhaust gases, relative to the rocket.

The thrust on the rocket is 34.7 MN. The gas exhaust velocity is 2.6×10^3 m s^{-1}.

Calculate the rate of change of mass of the rocket.

rate of change of mass = ... kg s^{-1} [2]

(c) The rocket fires its engine and its mass decreases from its initial mass m_o to a mass m. The change in velocity Δv_r of the rocket depends upon the exhaust velocity V of the gases, m_o and m.

The ideal rocket equation gives the relationship as:

$$\Delta v_r = V \ln\left(\frac{m_o}{m}\right)$$

(i) Show that the ratio $\left(\frac{m}{m_o}\right)$ is equal to $e^{-(\Delta v_r/V)}$

[1]

(ii) Use the relationship in **(c) (i)** to complete Table 7.1 below.

In this case V is 8.0×10^3 m s^{-1}.

Δv_r / 10^3 m s^{-1}	$\left(\frac{m}{m_o}\right)$
1.0	
2.0	0.78
3.0	0.69
5.0	0.54
6.0	0.47
	0.38
10.0	0.29
12.0	0.22

[2]

Table 7.1

(iii) Fig.7.2 is a graph of the mass ratio $\left(\frac{m}{m_o}\right)$ against the change in velocity Δv_r for a gas exhaust V of 2.6×10^3 m s^{-1}.

On Fig. 7.2, draw a second graph plotting all the data from the table in **(c) (ii)**.

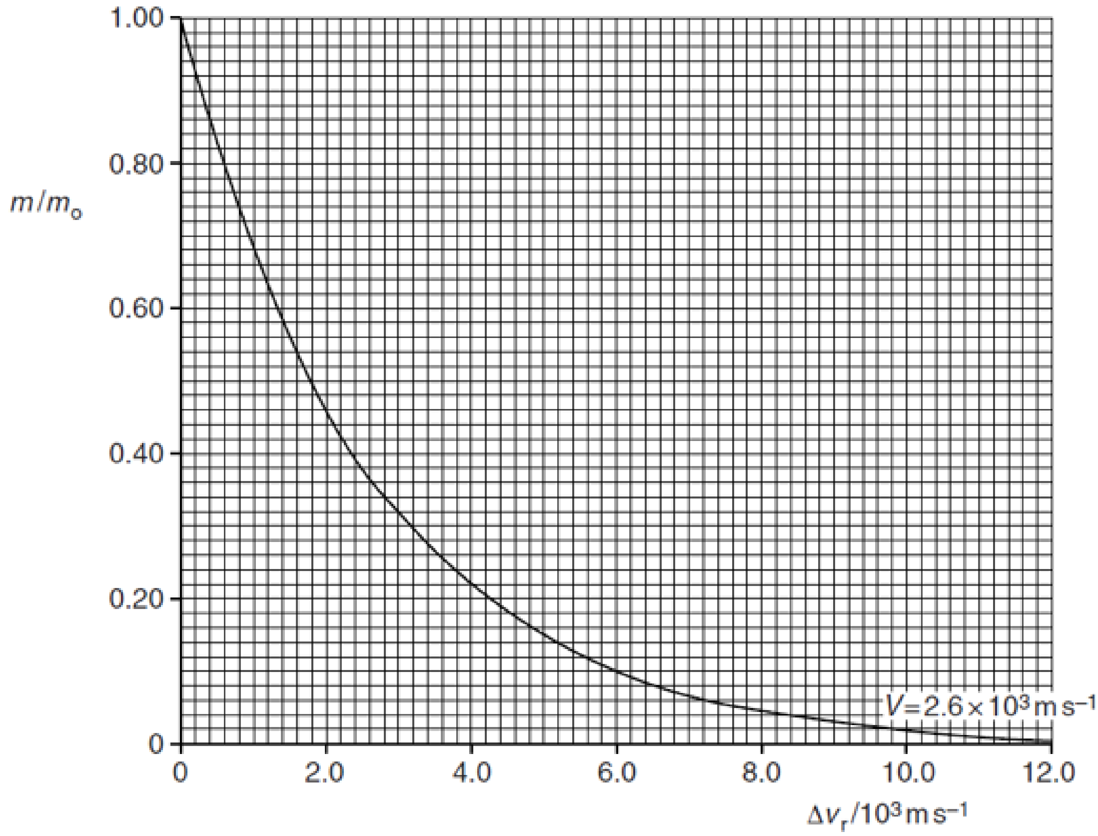

Fig. 7.2 [3]

(iv) The initial mass m_o of the rocket, including the fuel, is 2.04×10^6 kg.

The first burn of fuel gives $\Delta v_r = 5.0 \times 10^3$ m s^{-1}.

Use information from the graphs in **(c) (iii)** to calculate the difference in the mass of fuel used to accelerate the rocket by the same change in velocity Δv_r if its gas exhaust velocity V is 8.0×10^3 m s^{-1} rather than 2.6×10^3 m s^{-1}.

difference in mass = ... kg [3]

(d) A rocket launches a satellite, which orbits at a height h above the Earth's surface as shown in Fig. 7.3.

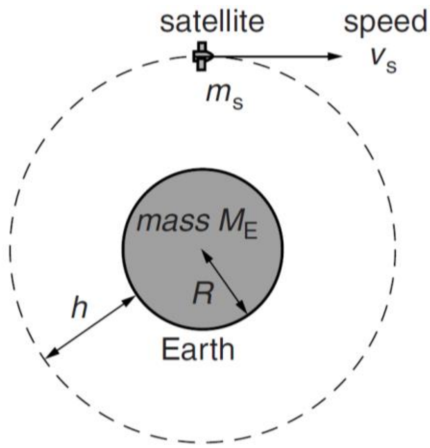

Fig. 7.3 (not to scale)

The satellite of mass m_s has speed v_s. The mass of the Earth is M_E and its radius is R.

(i) State the relationship for the gravitational potential energy E of the satellite in terms of relevant quantities given in Fig. 7.3.

….. [1]

(ii) Explain what is meant by the term *gravitational potential energy* of a mass such as a satellite.

…..

…..

….. [2]

(iii) Use the information given below to determine the height h of the satellite above the Earth's surface.

total energy of satellite	$E_T = -4.5 \times 10^9$ J
mass of satellite	$m_s = 152$ kg
speed of satellite	$v_s = 7.70 \times 10^3$ m s^{-1}
mass of the Earth	$M_E = 5.98 \times 10^{24}$ kg
radius of Earth	$R = 6.36 \times 10^6$ m

height above Earth = ... m [4]

[Total: 20]