Name of the Student:_____
Max. Marks : 20 Marks **Time : 20 Minutes**

Q1.

This question is about two applications of photon energy and momentum: positron emission tomography (PET) and a solar sail.

$$\text{The momentum of a photon is } \frac{\text{photon energy}}{\text{speed of light in a vacuum}}$$

(a) In preparing for a PET scan of a patient's brain, a small sample of a substance containing unstable nuclei is injected into the patient.
A positron is emitted when one of the unstable nuclei undergoes β^+decay.

Explain how the change in quark character in β^+decay affects the number of neutrons and the number of protons in the unstable nucleus.

_____

_____

_____

_____

_____

(2)

(b) The positron interacts with an electron, resulting in annihilation. As a result, gamma photons are produced.
The energy of each gamma photon is 0.52 MeV.

Calculate the momentum, in N s, of one of the gamma photons produced in this annihilation.

momentum = _____ N s

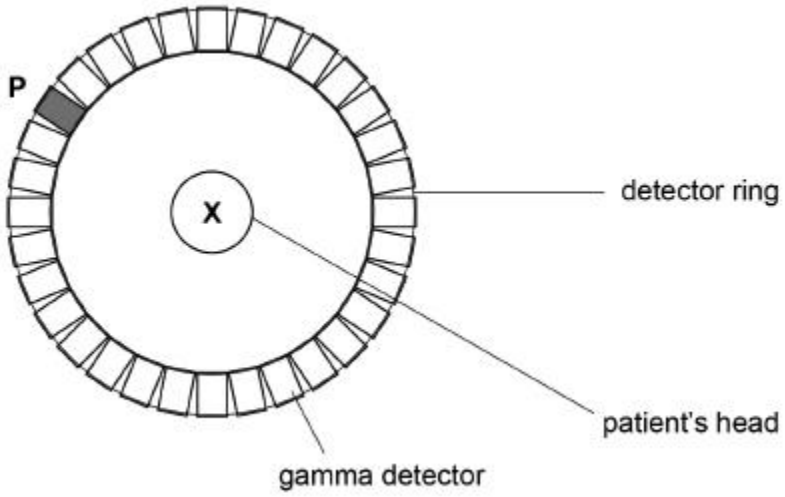
(2)

(c) **Figure 1** shows a cross-sectional view of the patient's head inside a ring of gamma detectors

Downloaded from www.merit-minds.com

during the PET scan.

Figure 1



A positron and an electron meet and annihilate at position **X** shown in **Figure 1**.
Assume they have negligible kinetic energy when they meet.

Gamma photons are produced in this annihilation and are detected. The arrival of one gamma photon at detector **P** triggers a signal. Detector **P** has been shaded in **Figure 1**.

Identify by shading any other detectors that will be triggered by this annihilation.

(1)

(d) Explain your answer to question **(c)**.

_____

_____

_____

_____

_____

_____

(2)

(e) **Figure 2** shows a stream of photons of light, emitted from the Sun, incident on a solar sail. A solar sail is an experimental spacecraft that uses photons of light to accelerate it.

Figure 2

Downloaded from www.merit-minds.com

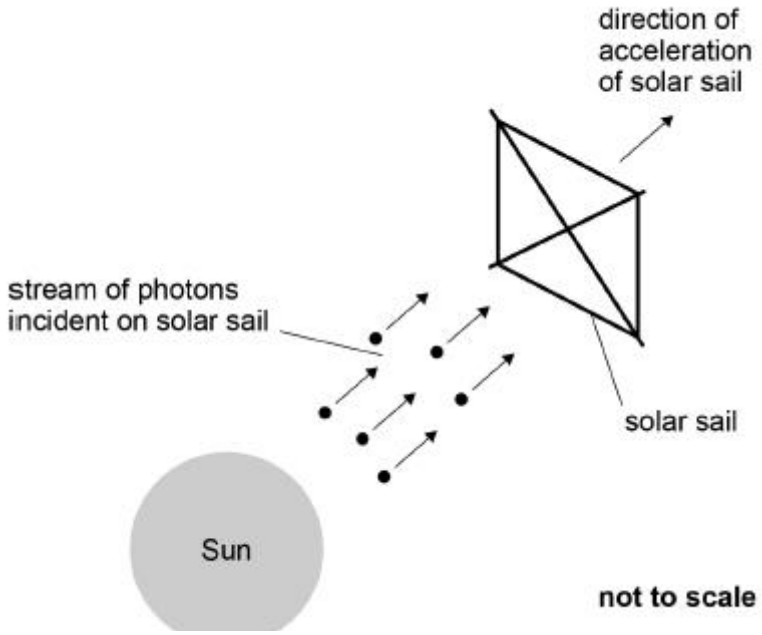
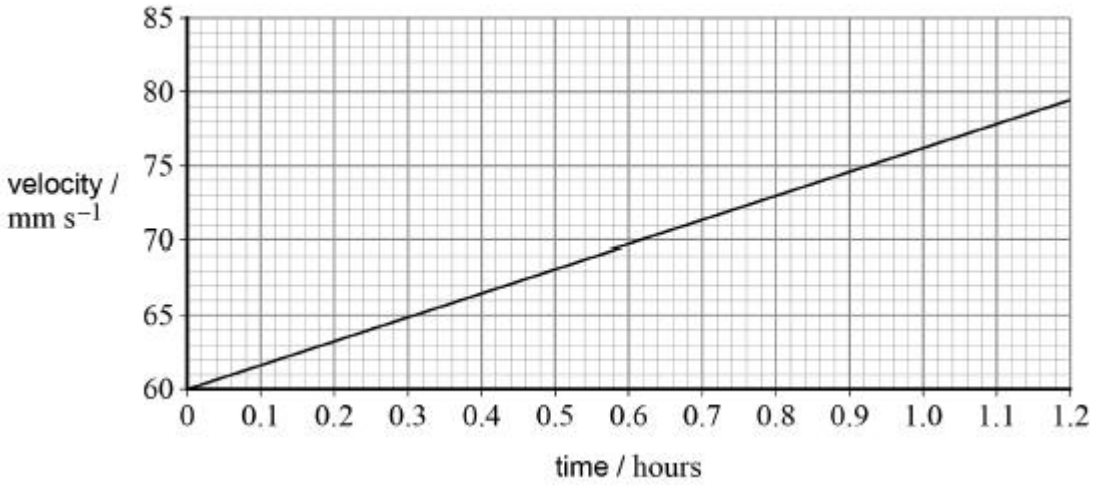


Figure 3 shows the velocity–time graph for the solar sail.

Figure 3



Calculate the acceleration, in m s^{-2}, of the solar sail.

acceleration = _____ m s^{-2}

(2)

(f) The reflectance of a surface is proportional to the percentage of incident photons that are reflected off the surface.

Explain the effect of increasing the reflectance of the solar sail on the acceleration. Assume gravity has negligible effect on the solar sail.

_____

_____

Downloaded from www.merit-minds.com

_____

_____

_____

_____

_____

_____

_____

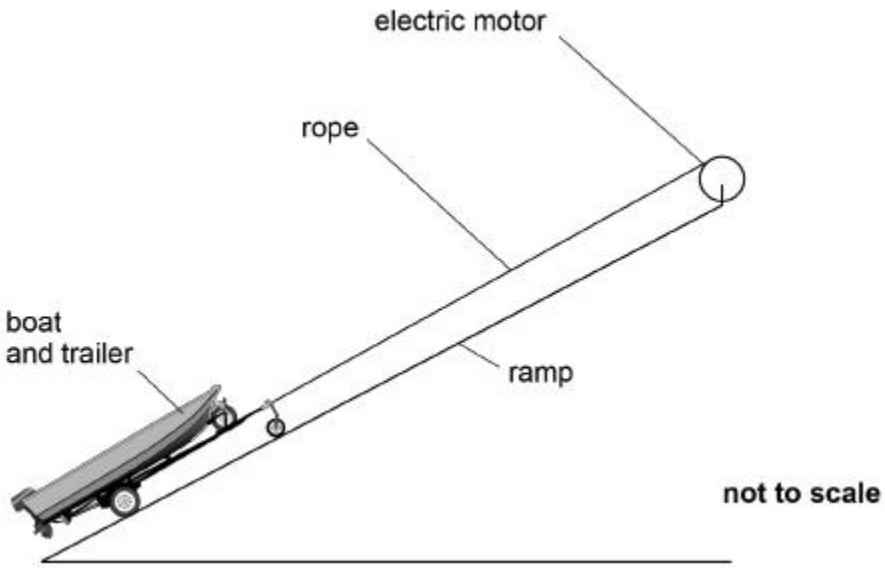
(2)

(Total 11 marks)

Q2.

This question is about the initial motion of a boat and trailer when pulled up a ramp as shown in **Figure 1**.

Figure 1

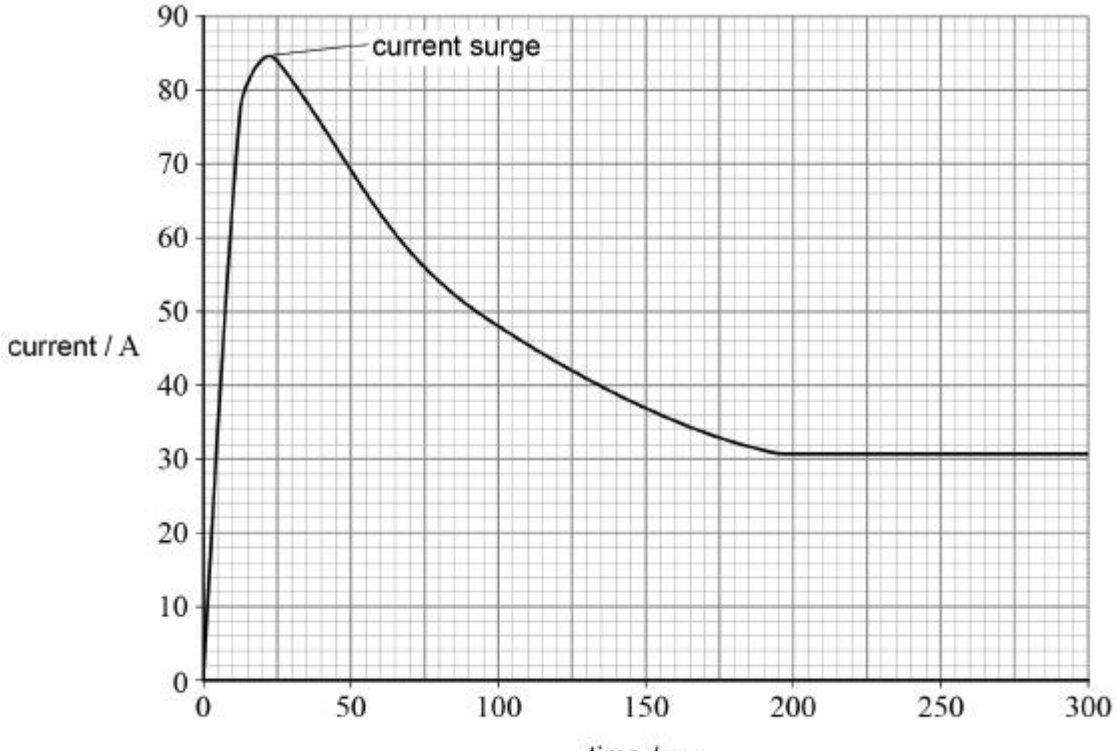


The boat and trailer are pulled by a motor which is connected to a 24 V battery of negligible internal resistance.

The motor is switched on at time $t = 0$
Figure 2 shows how the current in the motor's circuit varies with time.

Figure 2

Downloaded from www.merit-minds.com



(a) Determine the total energy input by the 24 V battery to the motor in the first 200 ms.

total energy input = _____ J

(3)

(b) The boat and trailer are initially at rest. In the first 200 ms the boat and trailer are raised through a vertical height of 3.3×10^{-2} m and the speed increases to 0.85 m s^{-1}.

Assume that all the useful energy output by the motor is transferred into kinetic energy and gravitational potential energy of the boat and trailer.
The boat and trailer have a total mass of 180 kg.

Determine the average efficiency of the motor during these first 200 ms.

average efficiency = _____

(3)

(c) Either of the circuits shown in **Figure 3a** and **Figure 3b** could be used to reduce the initial current surge.

Downloaded from www.merit-minds.com

Figure 3a

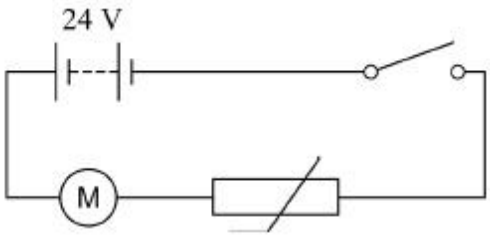
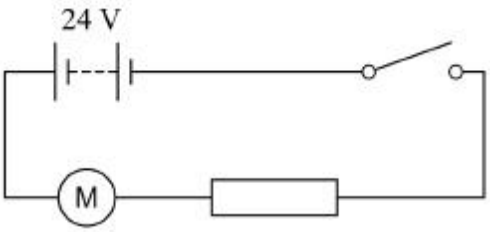


Figure 3b



The thermistor and the fixed resistor have the same resistance when they are at the temperature of the surroundings.

When the surge has ended, the boat and trailer continue to move at a constant speed to the top of the ramp.

Explain, with reference to the properties of the thermistor and the fixed resistor, why using the thermistor is preferable to using the fixed resistor.

_____

_____

_____

_____

_____

_____

_____

_____

_____

(3)

(Total 9 marks)

Downloaded from www.merit-minds.com