

Name of the Student: \_\_\_\_\_

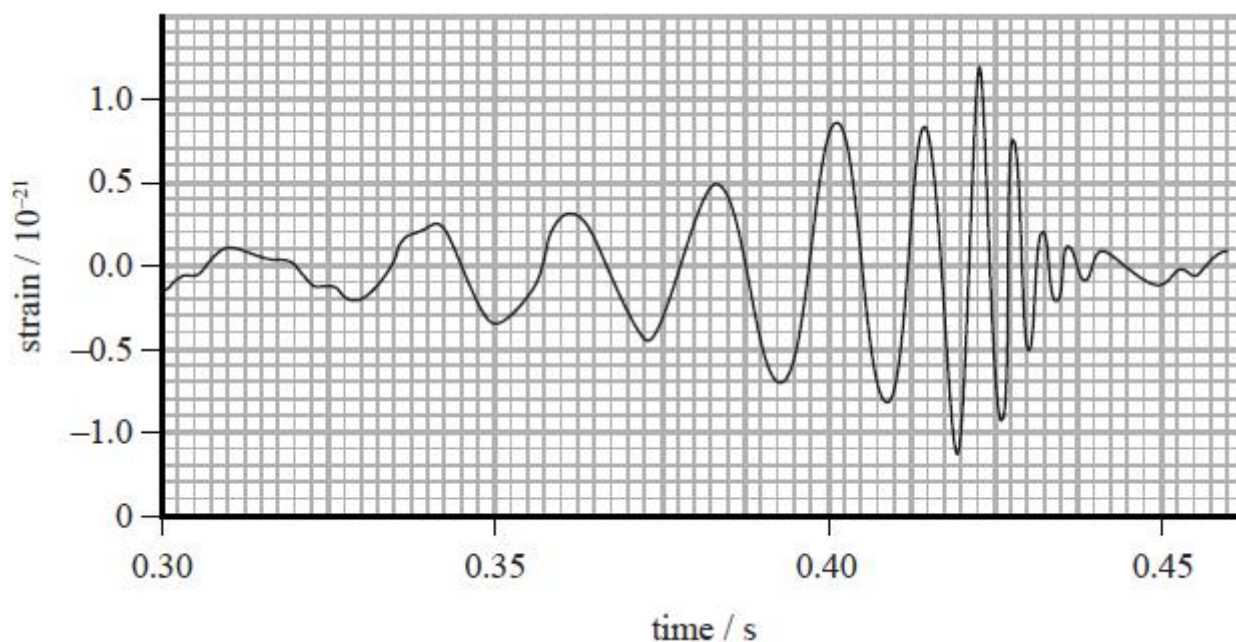
Max. Marks : 17 Marks

Time : 17 Minutes

Q1.

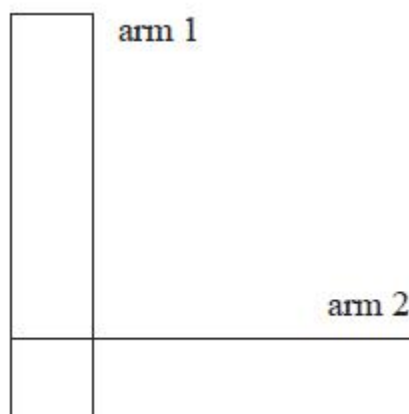
In 2016 scientists at the Laser Interferometer Gravitational-Wave Observatory (LIGO) announced that gravitational waves had been detected.

The signal they detected is shown on the graph.



Gravitational waves alternately compress and stretch matter by very small amounts as they pass through.

The LIGO detector has two arms, at  $90^\circ$  to each other, each 4 km long. As a gravitational wave passes the detector, the arms change length. The detector continuously compares the lengths of the two arms.



(i) An article states that 'the maximum change in the 4 km length of the arm is about 0.001 times the diameter of a proton'.

Determine whether this statement applies to the gravitational wave shown in the graph.

diameter of proton =  $8.8 \times 10^{-16}$  m

(3)

.....

.....

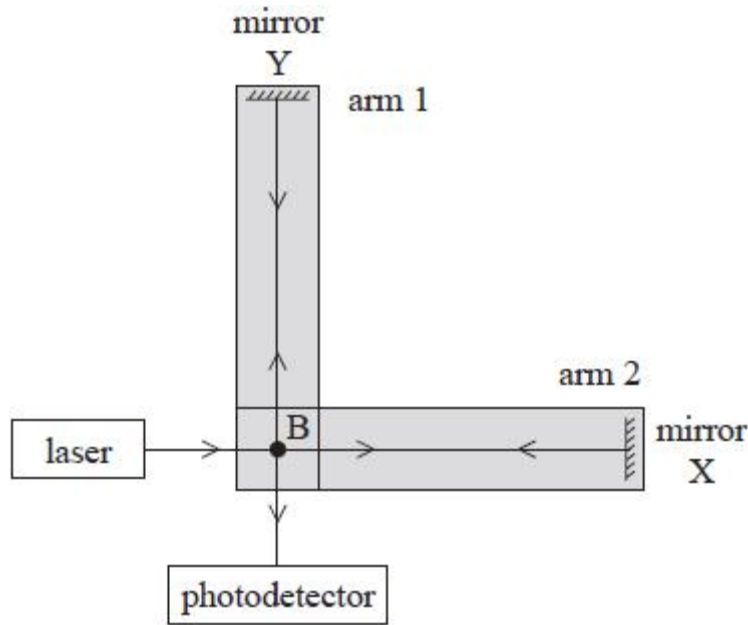
.....

.....

.....

.....

(ii) In the LIGO detector, any change in the lengths of the arms is detected using a laser beam and photodetector.



The laser beam is split into two at B, one beam travelling to one mirror and the other beam travelling to the other mirror. After reflection at the mirrors, the beams are recombined at B and reach the photodetector. The photodetector measures the intensity of the incident light.

The system is arranged so that when no gravitational waves are present, the beams have a path difference of half a wavelength at the photodetector.

Explain how the photodetector detects very small changes in the length of one arm, when the other arm stays the same length.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

(iii) The system could be arranged so that when no gravitational waves are present, the beams have zero path difference at the photodetector.

Explain whether using an initial path difference of half a wavelength is a more sensitive way of detecting changes in length than having an initial path difference of zero.

(2)

.....  
.....  
.....  
.....  
.....  
.....

**(Total for question = 9 marks)**

**Q2.**

Read the extract and answer the questions that follow.

Gravitricity is developing a new technology to capture and store the excess power generated by renewable energy resources. A large load is suspended by cables in a disused mineshaft. During periods of low power demand, excess generated power is used to winch the load upwards. During periods of high demand, the load is lowered down the shaft, causing electricity to be generated. The system can produce electricity at low power for several hours, or a short burst of electricity at high power.

(Source based on: <https://gravitricity.com/>)

(c) A load of  $5.0 \times 10^3$  tonnes is held stationary by several vertical steel cables. The strain on the cables is  $5.0 \times 10^{-3}$ .

Calculate the total cross-sectional area of the cables holding the load.

Young modulus of steel = 180 GPa

1 tonne =  $1.0 \times 10^3$  kg

(2)

.....  
.....  
.....  
.....

Cross-sectional area = .....

(d) The speed of the load in the shaft will depend on the variation of the electricity supply and demand throughout the day.

Explain why the total area of the cables will need to be greater than that calculated in (c) to limit the strain to no more than 0.005

(3)

.....  
.....  
.....  
.....  
.....  
.....

**(Total for question = 5 marks)**

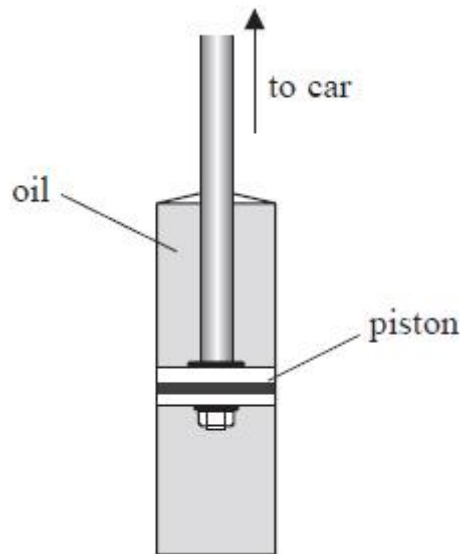
**Q3.**

The suspension system in a car includes a spring attached to each wheel as shown.



(Source: © Macrovector/Shutterstock)

The oscillations are heavily damped by a piston in the suspension system. The piston moves within a cylinder filled with oil, as shown. The oil has a high viscosity.



Explain why using oil of high viscosity will produce heavy damping.

(3)

.....

.....

.....

.....

.....

.....

**(Total for question = 3 marks)**