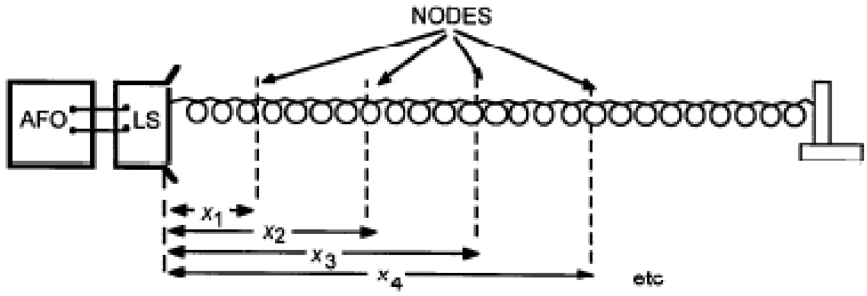
Scholarship Practice Questions

Question 1

US76 NZEST03

In an experiment to study longitudinal standing waves on a spring, a small light spring was stretched horizontally between a rigid clamp and the diaphragm of a loudspeaker. The loudspeaker was connected to an audio frequency oscillator and as the frequency was varied a series of standing waves was produced. In each case where a clearly defined standing wave was produced, the positions of the displacement nodes were measured from the point of attachment of the spring to the diaphragm as shown.



These distances and the corresponding frequencies were tabulated as below.

Stretched length of spring = 21.0 ± 0.1 cm

Frequency / Hz ± 5 Hz	Positions of nodal points / cm ± 0.1 cm				
290	6.8	13.8			
390	5.3	10.5	15.6		
490	4.3	8.4	12.6	16.7	
580	3.4	7.0	10.5	13.8	17.3

(a) Looking at the tabulated nodal points, would the diaphragm at 0.0 cm be expected to behave very nearly as a displacement node, as an antinode, or somewhere in between?

(b) On theoretical grounds, what would be expected at the rigid clamp at 21.0 cm?

(c) Using the answers above as well as the tabulated values, tabulate against each frequency the corresponding average internodal distance.

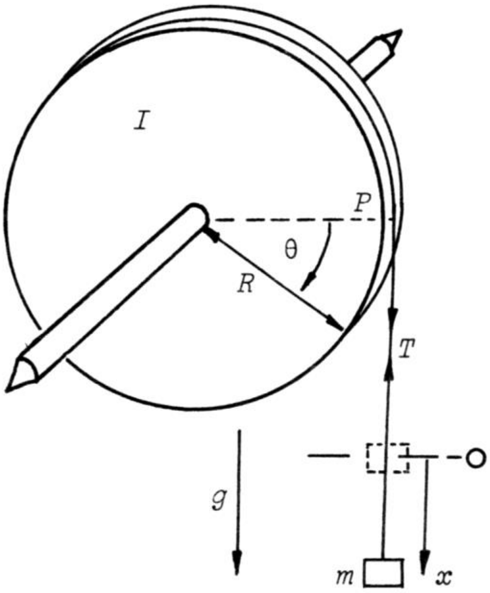
(d) State a numerical relationship between the internodal distance and the corresponding wavelength.

(e) Using this relationship, obtain values for the velocity of the longitudinal wave in the spring for each frequency. Calculate the average velocity over this range of frequencies and give an uncertainty for it.

(f) The behaviour of the wire in the spring was next examined by means of a stroboscopic light. When the light is flashed at very nearly the same frequency as the waves, the movements of the wire are seen in slow motion.
Describe the variation in motion of the portion of the spring between any two nodes as seen in the stroboscopic light.

Question 2
US81

A wheel of rotational inertia I and radius R rotates freely on its horizontal axis under the influence of the gravitational force on a mass m that is attached by a string of negligible mass to the rim. The mass descends under the influence of gravity and the tension T in the string. Both wheel and mass start from rest. Neglect friction in this discussion. Consider the situation shown when the mass has fallen by x and the wheel rotated by θ from the starting positions points O and P respectively.



(a) In terms of T, what is the torque on the wheel about its axis?

(b) What is the angular acceleration α of the wheel, using (a)?

(c) What is the net downward force on the mass?

(d) What is the downward acceleration a of the mass, using (c)?

(e) Show that $a = R\alpha$.

(f) Using (e), eliminate T from expressions in (b) and (d) to show that

$$a = \frac{mR^2}{I + mR^2} g$$

(g) What is the velocity of the mass after having fallen a distance x? Clearly state the physical principle or method employed by you in deriving your answer.

Question 3
UES81

The nuclear reaction ${}^{14}_{7}N + {}^{1}_{0}n \rightarrow {}^{14}_{6}C + {}^{1}_{1}p + Q$ occurs in the atmosphere converting nitrogen atoms into radioactive carbon. The reaction takes place at very low energies for the neutrons (ie, the kinetic energies of both N and n can be taken as zero). Q is the energy released in the reaction.
The following information will be needed:

$e = 1.6 \times 10^{-19}$ C
$m_p = 1.67 \times 10^{-27}$ kg

The total mass (${}^{14}N + {}^{1}n$) on the left-hand side of the reaction equation exceeds that (${}^{14}C + {}^{1}p$) on the right-hand side by 1.08×10^{-30} kg.]

(a) Write down the appropriate equations which express the conservation laws of momentum and mass-energy in the above reaction.

(b) Calculate the energy Q in MeV.

(c) Hence, using the results of (a) and (b), calculate the kinetic energy E_k of the proton to 5% accuracy.

(d) What are the approximate velocities of the proton and of the carbon-14 nucleus?

The carbon nucleus, ${}^{14}C$, produced in the above reaction is radioactive, ie, it naturally decays by emitting an electron according to the equation

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

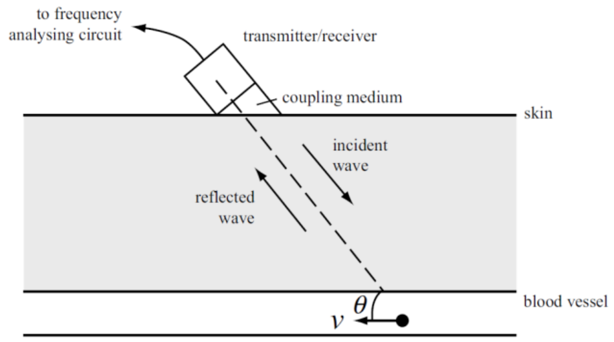
The decay reaction occurs at a rate such that half of the radioactive carbon nuclei have decayed in 5600 years, half the remainder decay in the next 5600 years, and so on.

(e) Two samples of wood, one cut from a living tree and the second from an archaeological sample many thousands of years old have their radioactivities compared. From a standard sample, the first emits 4000 electrons in a given time; the second emits only 500. Estimate the age of the second sample.

Question 4

NZS04
Doppler And Blood Flow

The velocity of blood flowing round the body can be determined using an ultrasonic transmitter/receiver and measuring the Doppler shift of the reflected wave. The diagram below shows the essential details of this process.



Reflected ultrasound from the moving blood is subsequently detected by the stationary transmitter/receiver probe shown in the diagram.

(a) Does the reflected ultrasound have a lower, higher or the same frequency as the transmitted wave? Explain.

(b) Three students derived the following possible equations for the total frequency change recorded by the detector. Only one equation is correct.

Identify the correct equation, giving reasons to justify your choice (a derivation of the correct equation is not required).

Student 1: $\Delta f = \frac{2fv}{c}\cos\theta$

Student 2: $\Delta f = \frac{2fc}{v}\cos\theta$

Student 3: $\Delta f = \frac{2fv}{c}(1-\cos\theta)$

where f is the transmitted frequency, Δf is the shift in frequency of the reflected waves, v is the blood velocity, c is the wave velocity and θ is the angle between the blood velocity and wave velocity.

(c) The velocity of ultrasound in human tissue and blood is 1.5×10^3 ms^{-1} and in the application described at the beginning of the question, a typical frequency of 5.0 MHz is used for the transmitted ultrasound. In one particular measurement a Doppler shift of 3.1 kHz was observed with the probe inclined at an angle of 30° to the direction of the blood flow. Calculate the speed of the blood.

(d) Blood flow through adjacent arteries and veins is in opposite directions. Suggest a difficulty in determining the direction of blood flow using the above technique.