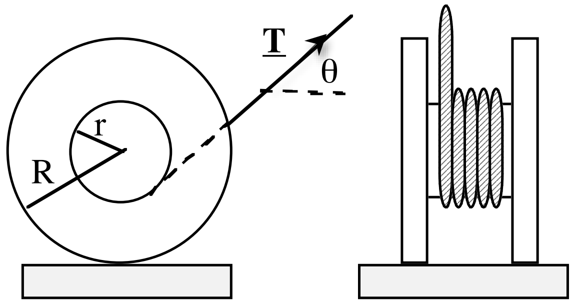
Question 1. **[14 Marks]**



A string is attached to the drum (radius r) of a spool (radius R) as shown in side and end views here. (A spool is device for storing string, thread etc.) A tension T is applied to the string at angle θ above the horizontal. The coefficients of kinetic and static friction between floor and spool are μ_k and μ_s respectively. We are interested in whether and when the spool will move left or right, and how this depends on the nature of the floor.

(a) Draw a free body diagram for the spool, showing the forces acting on it, for the case when it is in mechanical equilibrium. (The force vectors need not be to scale, but they should be in approximately the correct direction.)

(b) If it slides or skids, in which direction will it move when pulled by the string?

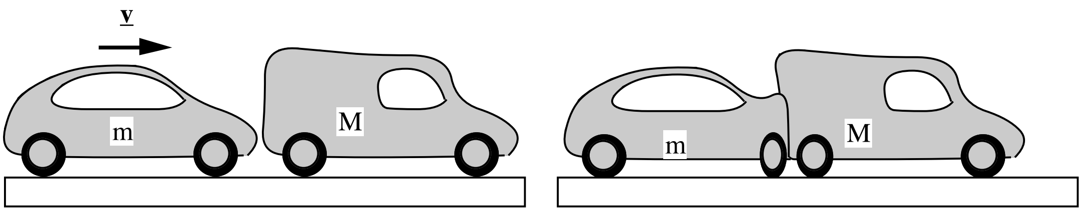
(c) If it rolls, in which direction will it move when pulled by the string?

(d) Showing all working, calculate the critical value of θ (call it θ_c) at which the condition goes from rolling to skidding.

(e) If $\theta > \theta_c$, and if you pull sufficiently hard on the string, which way does the spool move? (No explanation is required.)

Question 2. [26 Marks]

a)



A car, mass m = 800 kg, travelling at speed v, collides with the rear of a van, mass M = 1600 kg. The two vehicles remain in contact and travel a distance D = 2.2 m along the road, in the same direction as the velocity of the car. All eight wheels (four on each vehicle) leave skid marks for the full distance D. The coefficients for kinetic and static friction are $\mu_k = 0.80$ and $\mu_s = 0.95$ respectively.

(a) Showing your working, and noting any approximations you make or principles you use, derive an algebraic expression relating v to D and to the other data in this problem.

(b) Calculate the speed of the car before the collision. Express your answer in kilometers per hour.

(c) If the collision takes 100 ms, estimate the magnitude of the average force acting on the car during the collision.

(d) Estimate the magnitude of the average force that, during the collision, acts on a 70 kg person firmly held to the seat of the car by seatbelts.

(e) Imagine that you had to explain to a non-physicist the size of this force. Describe it quantitatively in several words.

(f) Suppose that the car were travelling at the same speed, that the van was initially stationary, that the collision were completely inelastic, but that, in this second case, the van did not have its brakes on during and after the collision. Would your answers to (c) and (d) be substantially different? In one or two clear sentences, explain your answer.

(g) From the definition of work, and considering a particle moving in one dimension, prove the Work-Energy Theorem.

Question 3 [27 Marks]

(a) A gas, not necessarily ideal, starts in state (P_1, V_1, T_1) and undergoes a thermodynamic process that takes it to a state (P_2, V_2, T_2), with the usual definitions of symbols. Write an expression for the work done *on* the gas by this process? Make sure you describe the meanings of any symbols used.

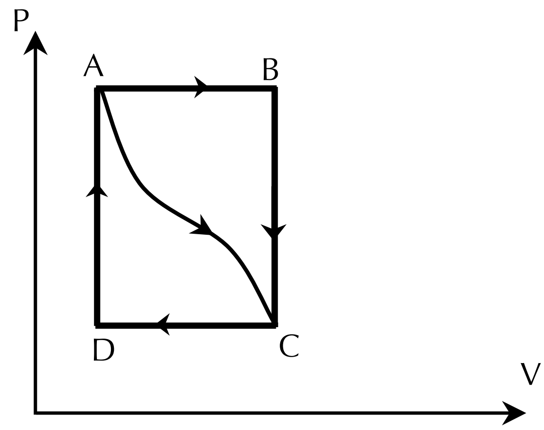
(b) (i) State the first law of thermodynamics, describing any symbols you use.

(ii) For a cyclic process what does this law then imply?

(c) (i) How much work is done on the steam when 2.00 moles of water at 100°C boils and becomes 2.00 moles of steam at 100°C at 1.00 atmosphere pressure? Assume that the steam behaves as an ideal gas. You may assume that the molar mass of water is 18.0 g/mole.

(ii) Determine the value of the increase in internal energy of the material as this occurs?

(d) A series of thermodynamic process takes place, as indicated in the PV-diagram in the Figure, between four states; A, B, C & D. The change in internal energy of a gas along the path from A to C is +800J, and the work done along the path ABC is -500J. In the parts of this question (below) make sure you include a full explanation of your calculations.



(i) How much energy must be added to the system as heat as the gas goes from state A through state B to state C?

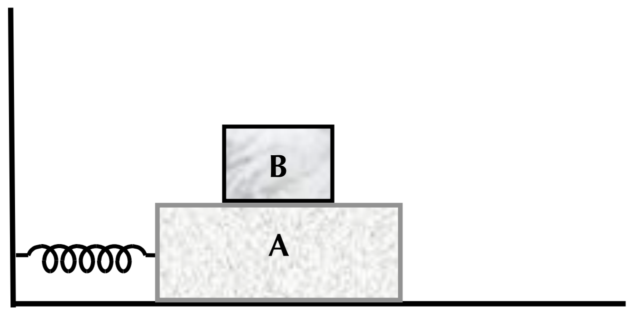
(ii) If the pressure at state A is 5 times that at state C, what is the work done in going from state C to state D?

(iii) What is the energy added to the surroundings by heat as the cycle goes from state C to state A along the path CDA?

(iv) If the change in internal energy going from state D to state A is +500J, how much energy must be added to the system by heat as it goes from state C to state D?

Question 4 [Marks 12]

(a) A large block, A, executes horizontal simple harmonic motion as it slides across a frictionless surface, connected by a spring to an immoveable wall, as shown in the Figure. A small block, B, rests on top of it. Suppose the frequency of the simple harmonic motion is f=1.50 Hz, and the coefficient of static friction, μ_S, between blocks A and B is 0.60.



Determine the maximum amplitude of oscillation that block A can have, if there is no relative motion between blocks A & B.

(b) Suppose now a third block, C, is placed on top of block B, while block A remains oscillating with the maximum amplitude determined in part (a). If the coefficient of static friction between blocks B and C is 0.50, what is the maximum frequency that the oscillation can now have, before block C starts to slip?

Question 5 [23 Marks]

(a) What general properties of a linear medium does the speed of a mechanical wave depend upon? Relate these properties together in an appropriate formula. Furthermore, for the special case of a transverse wave in a stretched string, give the specific formula for the wave speed. Describe any symbols that you use.

(b) (i) A transverse wave travelling on a taut string has an amplitude of 0.200 mm and a frequency of 500 Hz. It travels with a speed of 196 m/s. Write down an equation, in SI units, of the form $y = A \sin(kx - \omega t)$, that describes this wave.

(ii) If the string has mass per unit length of 4.10 g/m then determine the tension in the string.

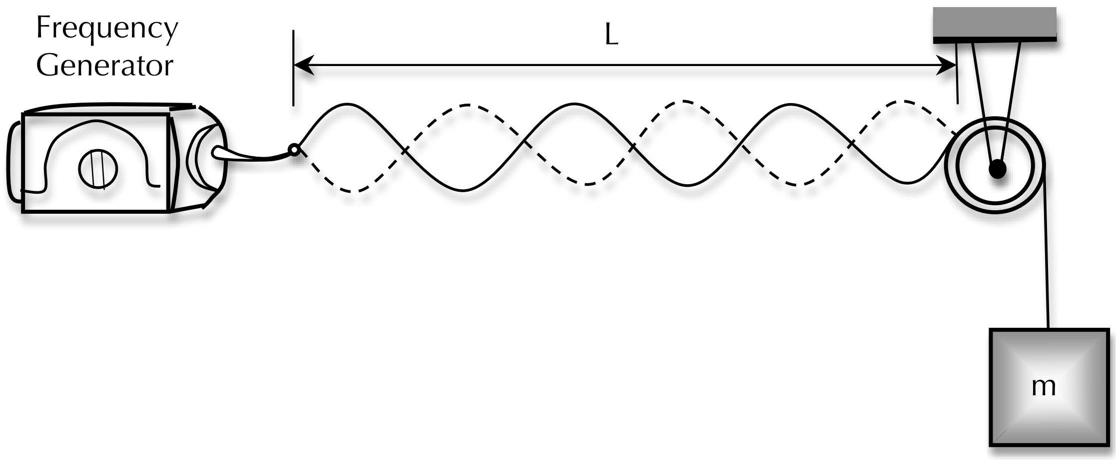
(c) A rope of mass m and length L is suspended vertically. Show that a transverse pulse travels the length of the rope in a time given by $T = 2\sqrt{\frac{L}{g}}$.

(d) If an object of mass M is suspended from the bottom of the rope in part (c), show that the time taken for the transverse pulse to travel the length of the rope is now given by
$T = 2\sqrt{\frac{L}{mg}}\left[\sqrt{M+m} - \sqrt{M}\right]$.

Question 6 [Marks 18]

(a) Explain how to tune two sinusoidal oscillators to exactly the same frequency using the phenomenon of beats.

(b)



In the arrangement shown in the Figure an object can be hung from a string that passes over a light pulley. The linear mass density of the string is μ=0.00300 kg/m. The string is connected to a frequency generator and set to oscillate at frequency f. The length of the string, between the pulley and the frequency generator, is L=1.50 m. When the mass m hung on the string is either 16.0 kg or 25.0 kg standing waves are observed; however no standing waves are observed for any mass between these values. What is the frequency that the string is vibrating at? Hint: the greater the tension in the string the smaller the number of nodes there are in the standing wave.

(c) What is the largest mass m for which standing waves could be observed?