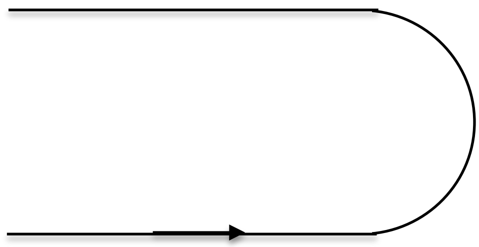
Question 1 (Marks: 20)

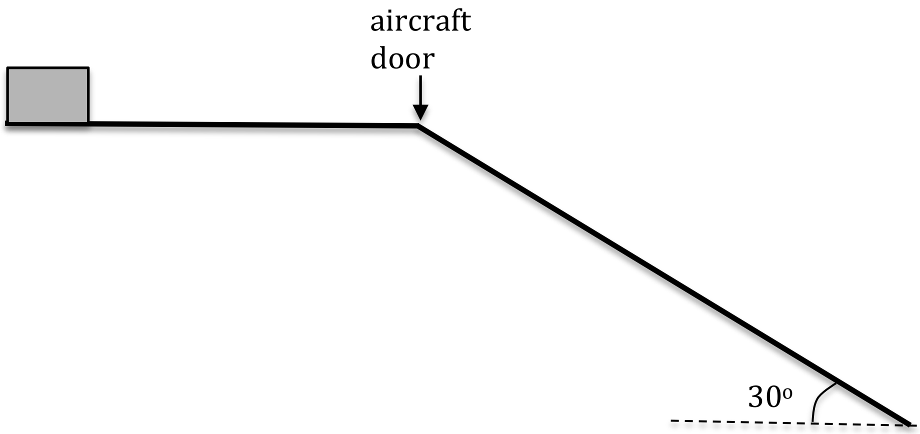
(a) A cyclist is initially travelling in the positive x direction. She makes a 180° turn with radius r, turning to the left (or anticlockwise viewed from above). Her speed is constant at v throughout. Using **i**, **j**, **k** notation, write expressions for

(i) her velocity halfway through the turn

(ii) her acceleration halfway through the turn.



(b) A rectangular crate of mass 35 kg is being unloaded from an aeroplane, as shown in the sketch. Inside the plane, it is pushed 2.0 metres across a rough horizontal floor to the door of the aircraft at a constant speed of 1.0 $m.s^{-1}$.



Draw a free body diagram showing the forces acting on the crate while it moves across the horizontal floor.

(The coefficient of friction is not negligible.)

(c) What is the acceleration of the crate while it is being pushed across the horizontal floor of the aircraft?

(d) The crate is pushed out the cargo door of the aeroplane, with an initial velocity of 1.0 $m.s^{-1}$ down the ramp, onto a rough ramp joining the cargo door to the ground. It then slides down the ramp. The ramp makes an angle of 30 degrees to the horizontal, and the coefficient of kinetic friction between the ramp and the crate is 0.40. The height of the cargo door above the ground is 10.0 m.

(i) Draw a free body diagram showing all the forces acting on the crate while it is on the ramp.

(ii) Determine the magnitude and the direction of acceleration of the box while it is sliding down the ramp.

Question 2 (Marks: 20)

(a) (i) State the principle of conservation of mechanical energy, including any conditions of its application.

(ii) What is a completely elastic collision? One short sentence will do.

(iii) A particle of mass m travels at initial velocity v in the positive direction along the x axis, with respect to the lab frame. At the origin, it strikes a second particle, also of mass m, stationary in the lab frame. After the collision, the second particle is observed to travel in the direction of the positive x axis with speed v_2. Assuming that the collision is completely elastic, derive expressions for the velocities of both particles after the collision. State clearly any assumptions or principles used.

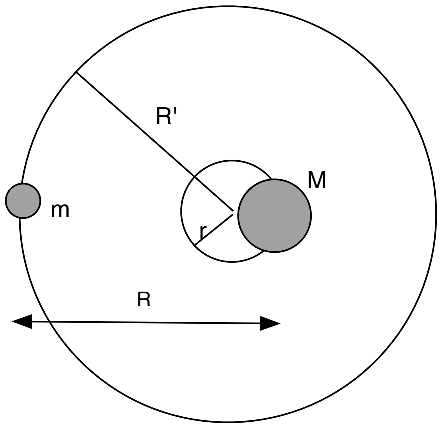
(b)

A small solid sphere of mass m and radius r is initially rolling without slipping on a horizontal table. It reaches the start of a curved, rising surface, as shown in the sketch. It continues to roll without slipping until it stops at a point on the curve. Stating all assumptions and principles used, derive an expression for the height h that the sphere rises above the table before stopping. Include a clear statement about the effect of the friction acting between the sphere and the surfaces.

(c) Write an expression for the centre of mass of a continuous body. From that definition, derive an expression for the position of the centre of mass of a thin, uniform rod of mass m and length L about one end. The rod lies on the x axis between x = 0 and x = L.

Question 3 (Marks: 10)

Astronomers look for planets orbiting other stars by studying the motion of stars due to the gravitational effect of their planet or planets. Consider a star that has mass *M* and a single planet, mass *m,* at distance of *R* from the centre of the star. (Using a technique we'll study in Physics 1B), an astronomer determines that the star (the star, not the planet) orbits the common centre of mass of the star-planet system in a circle of radius r and period *T* (which is the 'year' for this system).



(i) Write or derive an expression for the centripetal acceleration of the star due to the presence of its planet in terms of some of the variables listed above.

(ii) Use Newton's second law to derive an expression for m in terms of *r*, *T* and other terms.

(iii) The mass M of the star can often be determined from its brightness, colour and distance away. Stating any laws or principles used and explaining your reasoning carefully, derive an expression for *R* in terms of *m*, *M* and *r*.

Question 4 (Marks: 25)

In this section make use of the data provided in these tables.

Specific Heats and Thermal conductivities of selected metals

Substance	**Specific Heat** *c*, **($Jkg^{-1}K^{-1}$)**	**Linear thermal expansion coefficient** **α, ($^{o}C)^{-1}$**	**Thermal conductivity** *k*, **($Wm^{-1}K^{-1}$)**
Aluminium	910	24×10^{-6}	205.0
Brass	377	19×10^{-6}	109.0
Copper	390	17×10^{-6}	385.0
Lead	130	29×10^{-6}	34.7
Steel	456	11×10^{-6}	50.2

Water

Quantity	**Value**
Specific Heat (liquid)	4186 $Jkg^{-1}K^{-1}$
Latent heat of Fusion	3.33×10^{5} Jkg^{-1}
Latent heat of vapourization	2.26×10^{6} Jkg^{-1}
Density (at 4.00^{o} C)	1000 kgm^{-3}
Melting point (at 1 atm)	0.000 °C
Boiling point (at 1 atm)	100.0 °C
Volume expansion coefficient (β) (at 20^{o}C: you may assume it is constant between 4^{o}C and 100^{o} C)	207×10^{-6} $(°C)^{-1}$

(a) An enclosed container contains 15.0 mols of an ideal monatomic gas at 25.0 °C.

(i) How many degrees of freedom does one molecule of the gas have?

(ii) Describe what type of movement each of these degrees of freedom corresponds to.

(iii) How much energy would need to be added to increase the temperature of the gas by 10.0 °C?

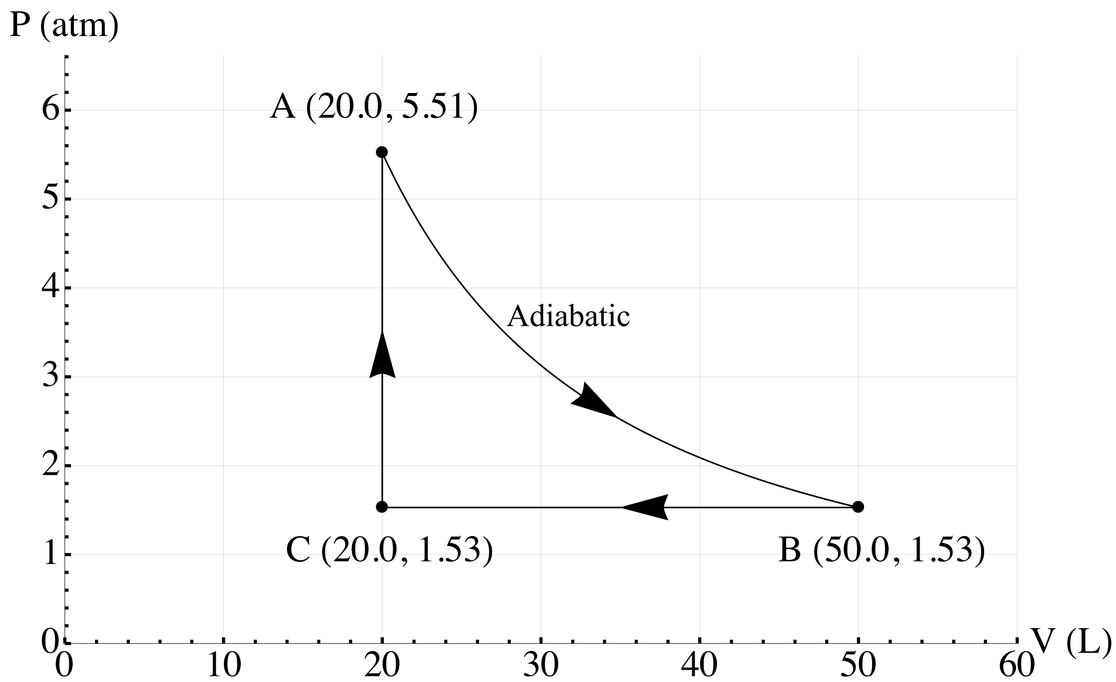
(b) A circular aluminium disk has a surface area of 20.0 cm^2 and a height of 1.00 cm. The plate is initially at 20.0 °C and is then placed in an oven at 180.0 °C. Aluminium has a density of
2.70 gcm^{-3} at 20.0 °C.

(i) What is the change in the height of the plate as it is heated?

(ii) What is the change in the surface area of the plate as it is heated?

(iii) How much energy has been added to the aluminium plate during this process?

(c)



2.50 mols of a diatomic gas undergoes a cycle as shown in the diagram above. The pressure and volume at each of the points, A, B and C are shown on the diagram in brackets with the volume preceding the pressure. Process A→B is an adiabatic process. To get the gas from state B to state C 16,200 J of heat energy is removed. Note, in the diagram above the volume is given in litres and the pressure is given in atmospheres.

(i) What is the temperature of the gas at A?

(ii) How much work is done on the gas as it goes from B →C?

(iii) How much heat is added to the gas as it goes from C →A?

(iv) How much work is done on the gas as it goes from A →B?

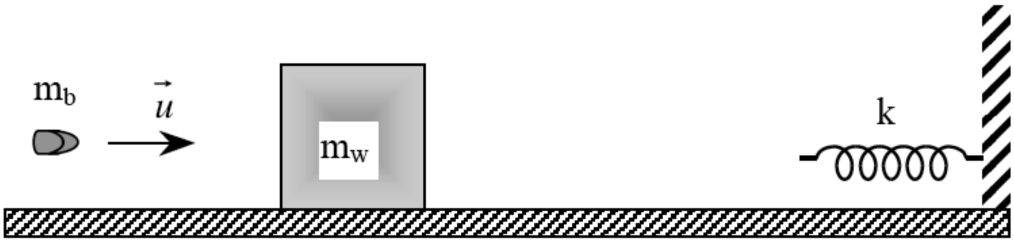
Question 5 (Marks: 25)

(a) A ball moves in a circular path with a radius of 3.0m and at a constant speed of 4.0m/s.

(i) Calculate the period and frequency of the motion of the ball.

(ii) Assume that ball is at (x, y)=(0.0, 3.0m) at time t=0.0s. Determine the equations for the x and y components of the position of the ball.

(b) An experiment is designed to calculate the speed of a bullet. The bullet is fired into a wooden block, becoming lodged in it with no loss of material. The block + bullet is then free to slide on a horizontal surface, finally compressing a spring, as shown in the diagram. The spring obeys Hooke's law.



The masses of the bullet and the wooden block are m_b = 4.50g and m_w = 1.63 kg, respectively.

(i) First, an additional experiment is conducted to determine what the spring constant, k, is for the spring. The block is suspended from the spring. This extends the spring a distance of 14.0cm. From this information calculate the value of k.

The bullet is then fired into the block, becoming lodged in it. The combined block + bullet system then slides a distance of 45.0cm before compressing the spring 13.0cm. Assuming the horizontal surface to be frictionless, calculate:

(ii) the speed of the combined block + bullet system immediately before the spring is compressed,

(iii) the initial speed of the bullet.

(c) A man sits by the open window of a train that is moving at a speed of 20.00 m/s through a railway station in an easterly direction. A woman is standing on the platform and watching the train come towards her. The air is still and the speed of sound in it is 343 m/s. The train emits a whistle with a frequency of 900.0 Hz as it enters the station.

(i) What frequencies for the whistle do the man and the woman hear, respectively?

The wind now begins to blow towards the east at a speed of 10.00 m/s.

(ii) What frequencies do the man and woman now each hear?