Kinematics and Dynamics

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1 Important concepts

All good mechanics problems start with a diagram. Make sure to draw it clearly. These problems will often include SUVAT equations. Here are some reminders: $v = u + at$, $s = ut + \frac{1}{2}at^2$, $s = \frac{v+u}{2}t$, $v^2 = u^2 + 2as$. Where s is displacement, t is time, u is initial velocity, v is final velocity and a is acceleration. Note that these equations only work for **constant acceleration**.

Question 1 - Round 1 Olympiad 2020 (2 marks) Estimate from what height, under free fall conditions, a heavy stone would need to be dropped for it to reach the surface of the Earth at a speed of 330ms^{-1}

Question 2 - Isaac Physics (2 marks) A lost astronaut lands her spaceship on an unknown planet. She decides to work out the value of the acceleration due to gravity on this planet so that she can check her onboard computer and find out her location. She knows that on Earth (where $g = 9.81\text{ms}^{-2}$ downwards) she takes 1.0s to jump up and land again. On this planet, a jump takes 1.4s. What is the magnitude of the downward acceleration due to gravity on the strange planet? Assume she can jump up at the same speed on any planet, and give your answer to 2 significant figures.

2 Statics and Dynamics

The study of statics and dynamics involves **forces**. The central equation around which the principle revolves if $F = ma$. What we must keep in mind is that in this equation, both the force and acceleration are **vector** quantities, and so they must be resolved before applying the law.

N.B. The force of friction is usually modelled as being proportional to the normal contact force experienced by a body. The constant of proportionality, represented by μ depends on whether the body is moving or if it is static. If the body is static, the frictional force will be equivalent in magnitude to the "moving" force applied on the body, up to the limit of μR, where R is the reaction force. As soon as the force on the body exceeds this limit, it will begin to move.

Question 3 - PAT 2014 (5 marks) Two masses m_1 and m_2 are connected by a massless, non-extensible string supported by a massless pulley attached to a table with a hole in the middle. The mass m_2 is dangling off the edge of the table below the hole, whereas the mass m_1 is on the right hand side of the table. Assuming no friction, derive an expression for the acceleration of the masses and for the tension of the string. Now, consider friction acting on the table but not on the pulley. Friction force F_{fr} is proportional to the normal contact force on the mass; $F_{fr} = \mu_s mg$ or $F_{fr} = \mu_d mg$ depending whether the mass is at rest ($\mu_s =$ static friction coefficient) or in motion ($\mu_d = =$ dynamic friction coefficient). Both coefficients are known. Derive expressions for the acceleration of the masses and for the tension of the string. What condition needs to be satisfied for m_1 to accelerate?

3 Extension questions and further reading

Here are some extension problems:

Question 4 - 200 Puzzling Problems How high would the world record high-jumper be able to jump on the moon? Solve algebraically, writing down your assumptions, then look up the record and solve.

Question 5 - Physics Problems for Aspiring Physical Scientists and Engineers In a game of cricket, a batsman, Bob, strikes the ball towards a fielder, Fred, who is perfectly positioned to catch it. Assume the batsman, his bat and the fielder are all at roughly the same height. The angle of elevation of the ball to the fielder(that is, the angle to the horizontal at which the fielder has to look up to see the ball) is ϕ. Show that the rate of change of $\tan\phi$ is constant as the fielder tracks the ball, and derive an expression for that constant. Neglect resistive forces.

In terms of wider reading, you can check out the Isaac Physics website with loads of great mini-lessons and challenging problems on these topics, or to the BPhO website, who also provide an Olympiad question bank.

Thank you all for coming!