Fun Physics Questions

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This document was prepared for IA Physicists at St John's College, in Michaelmas 2009.

Most of these problems are pretty difficult – so feel free to ask for help if you want some clues. I've tried to classify them (roughly) into three difficulty levels, but one person's hard problem is another's easy one, so the ratings are necesserally subjective.

Many of these problems involve situations that seem at odds with the laws of physics you're taught in lecture, but which on closer scrutiny are not at all. My hope is that these problems will make it clear that however nice the models we teach you are, they're only as good as the physicist who uses them.

None of these problems are entirely my own; they are mostly loosely adapted from other sources. I have tried to give attribution wherever possible.

Enjoy!

I. REASONABLY EASY IF YOU THINK ABOUT IT

1. A ball bounces against a wall and the collision is elastic, so that the ball comes in at a speed v, and leaves at a speed v. Energy is conserved.

   Now consider a frame moving with the ball before the collision. In that frame, the ball is initially at rest, and then moves at a speed $2v$. Energy is not conserved! What happened? [1]

   There is an easy solution to this problem, which you should be able to find after some thought. There is a much more advanced answer which is infinitely more satisfying, but it requires some physics you wouldn't have encountered. Try Googling 'Noether's Theorem' if you're interested.

2. $g = 9.81$ and $\pi^2 = 9.87$. That's pretty close! Coincidence? [1]

   (It's possibly misleading to put this problem in this section. The answer is very basic, but it's fiendishly difficult to get. I've only ever had one person solve this problem by themselves.)

3. A block of mass m is placed on a conveyor belt moving at a speed u. Originally, the block slips on the belt, but eventually it ends up moving with the belt at a speed u.

   What's the total work done by the conveyor belt motor in the frame of the conveyor belt? In the ground frame? Are they different? Why or why not? [2]

4. Consider the following two situations

   - A string is attached to a marble and threaded through the centre of a cylinder. The marble rotates, and the string is slowly pulled in through the bottom of the cylinder (Figure 1).
   - A string is attached to a marble and wound round a cylinder. The marble rotates, and as it rotates, it winds further around the cylinder (Figure 2).

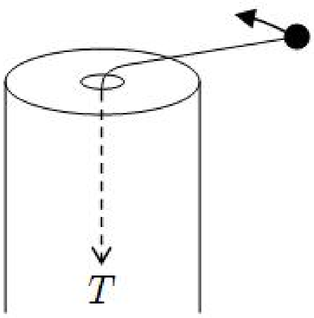

FIG. 1.

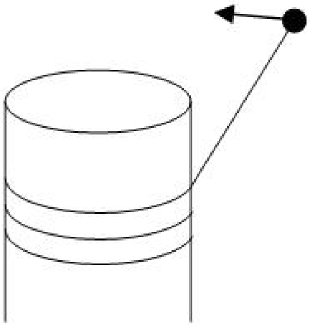

FIG. 2.

   In each case, work out the speed of the marble after a certain time has passed, given an initial speed. Is any conserved quantity not conserved in either case?[4]

5. How large is the sun's pull on the moon compared to the earth's pull? Given the moon orbits *us* you'd hope the earth's pull was larger, right? Sadly, that's not the case! The sun pulls more than twice as hard!So why don't we lose the moon?**??**

6. A body's center of mass moves only if an exeternal force is applied, but you can get to the other side of the room in a chair without letting your feet touch

the floor. If all your twistings and contortions are internal forces, what provides the external force? [5]

7. Why is the cushion on the side of a pool table higher than the center of the balls?Wouldn't you get better rebound if the cushion were at the center's height? [5]

8. Why, on some toilet paper dispensers, can I get a long piece of toilet paper without tearing if the roll is fat, but when the roll has been nearly used up, the paper inevitably breaks too soon, giving only short pieces? [5]

9. Try the following party trick: put a bottle down on a table, and attach a long string to the ceiling *directly above* the bottle's mouth. Attach a ball to the other end of the string, so as to form a pendulum long enough to hit the bottle.

   Now, challenge your friends to let the ball go so that it *misses* the bottle the first time it swings past it, but *hits* it on the return swing.

   They might be in for a rather long evening. Why is it impossible to set up a swing as desribed above?[5]

10. Consider a pendulum in which the bob at the end of the string is a sphere full of water. The pendulum is set going, and the water is allowed to (slowly) drip out of the sphere. How, if at all, will the period of the pendulum be affected? Try and do some calculations...

11. Does the weight of an hourglass depend on whether the sand is flowing? If some of the sand is in free fall, won't the weight of the hourglass be less?[5]

II. A BIT HARDER...

1. A car of mass m is at rest, and accelerates to 10m/s to the right, using a certain amount of fuel. Its increase in kinetic energy is $50m$J.

   To an observer skating by at 10m/s to the left, however, it looks like the car has accelerated from 10m/s to 20m/s, increasing its kinetic energy by $150m$J. Yet, it agrees that the same amount of fuel has been used.

   Is fuel more efficient in the moving frame? [1]

2. In figure 3, a mass hangs from the ceiling. A piece of paper is help up to obscure three strings and two springs; all you see is two other string protruding from behind the paper, as shown. How should the three strings and two springs be attached to each other and to the two visible strings (different items can only be attached at their endpoints) so that if you start with the system at equilibrium and cut a certain one of the hidden strings, the mass will rise up? [3]

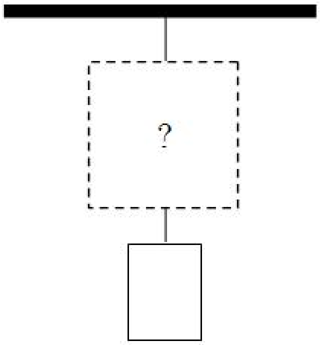

FIG. 3.

3. Artifical satelites don't orbit the earth forever. Eventually, the earth's atmosphere, thin as it may be up there, will bring them down. But did you know that the linear speed of a satellite in a nearly ciruclar orbit will *increase* because of the air drag?In fact, the satelite will experience an acceleration forward along its path, as if the air drag were turned around and were pushing the statelite along. How comes? [5]

4. Hold a ruler horizontally on yuor index fingers, and slide you fingers together smoothly. You'll find that the ruler does not slide smoothly over your fingers; it slides first on one finger, then on the other, and so on. Why?[5]

5. A simple conservation-of-momentum calculation will show you that if a moving object hits a stationary object of the same mass, the first object stops.

   Yet, pool enthusiasts know that it's possible to get a 'follow shot', in which the cue ball follows after the ball with which it has collided, or a 'draw shot', in which the cue ball returns after the collision. How do you set up these types of shot?[5]

6. The twirling ice skater has long been used as an example of the conservation of angular momentum. When they pull their arms in, they lower their moment of inertia and therefore spin faster, due to conservation of angular momentum.

   That's all nice and well, but the truth is that noone really understands angular momentum intuitively. Can you make this slightly easier to understand by explain the speeding up in terms of *forces* instead?[5]

III. *REALLY* HARD!

1. Imagine taking a lasso, looping it over the top of a perfectly conical mountain, and using it to climb the mountain. Clearly, for a very "tall and sharp"

mountain, this will work. If the mountain is very "small and fat", it won't - the lasso will just slip over the top.

What is the "limiting" angle, past which the lasso will slip?[3]

Answer the question for two types of lasso:

- A lasso with a "sliding loop" that can change size (sort of like a hangman's noose).
- A lasso with a loop of fixed size, tied there with a knot.

2. A ball lies on a smooth square smooth billiard table with no holes. The ball is struck. The ball bounces on the walls according to the usual laws of physics (angle of incidence = angle of reflection).

   The ball can either follow the same path for ever (for example, if you whack it straight up), or it can follow a never-repeating path.

   What's the condition on the original whack for the motion to be ever-repeating?[6]

3. Two spaceships float in space and are at rest relative to each other. They are connected by a string, which is strong, but cannot withstand an arbitrary amount of streching. At a given instant, the spaceships simultaneously (relative to their initial inertial frame) start accelerating in the same direction (along the line between them) by putting their identical engines on identical settings. Will the string ever break?[3]

   There is a rather hard and involved answer to this problem which uses no more relativity than we teach you in IA. It turns out there's another lovely and very elegant answer, but it requires a teeny bit of general relativity. Google the 'correspondence principle' if you're interested.

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[1] Dr Sanjoy Mahajan

[2] Dr Andrew Pawl

[3] David Morin, *Introduction to Classical Mechanics*, Cambridge University Press, 2007

[4] MIT 8.01 Course

[5] Jearl Walker, *The Flying Circus of Physics*, John Willey and Sons, 1977

[6] Michalewicz and Fogel, *How to Solve it: Modern Heuristics*, Springer, 2002