Physics 100: **Solutions** to Homework Assignment #3

Was Due on Friday, February 9at the Beginning of Class

Section 1. **Warm-up! Fill-in-the-Blanks (1 pt each)**

1. An object falling at its terminal speed is not (is/isn't) in a state of free-fall.
2. A Space Elephant exploring the deep outer regions of space where there is very little gravity has just as much mass/inertia as it does on Earth, but much less weight.
3. The acceleration vector of an object points in the same *(same/ opposite/ different)* direction as the the net force acting on the object.
4. The acceleration of a falling object that has reached its terminal velocity is equal to zero.
5. The two principle factors that affect the force of air resistance on a falling object are frontal area and speed (relative to the air) of the object.
6. An apple weighs 1 N. Therefore, its mass is 0.1 kg.
7. The acceleration of a 300,000 kg jumbo jet just before takeoff when the thrust on the aircraft is 120,000 N is 0.4 m/s2.
8. When a parachutist falls through the sky at constant velocity, he feels the upward tug on on his harness from the parachute and the downward pull due to gravity. In this case, the upward force is equal to/,*(equal to/ less than/ greater than)* the force of gravity.
9. As a parachutist falls, but before she reaches terminal velocity, her speed is increasing *(increasing/ decreasing/ remains the same)* while her downward acceleration is decreasing*(increasing/ decreasing/ remains the same)*.

Section 2. **Short Answer Questions (2 pts. each)**

10. If you push a crate with a force of 250 N across the floor in a straight line at a constant speed, (A) is the crate in equilibrium? (B) Is friction acting on the crate, and if so, how much force and in what direction is it acting?

    Answer: (A) Yes, the crate is in (dynamic) equilibrium as it's motion is remains unchanged (constant speed; straight line). If something is in equilibrium, the net force acting on it is zero. Therefore, (B) Friction must be acting on the crate to cancel out the force you're applying, meaning that it has a magnitude of 250 N and points in the direction opposite to the direction you're applying the force.

11. Consider a heavy crate sitting on a level floor. You push against it with a force of 300 N, but you're not strong enough to move it (i.e. its acceleration and speed both remain zero). As you push against the crate, (A) what is stopping you from moving it? (B) How much force is this something providing, and in what direction? After you push on the crate for a few minutes, you tire out a bit and are only able to push with a force of 200 N. (C) Will the crate begin moving, now? If not, (D) what is preventing the crate from moving and (E) how much force is it providing and in what direction?

    Answer: Because the crate is not accelerating, the net force on it must be zero. Since you are providing 300 N of force, then something must be providing an opposing force. In this case (A) (static) friction is stopping you from moving the crate by (B) providing a force of 300 N force in the opposite direction of the force you are providing. When you tire out and can only push with a force of 200 N, the (C) crate will still remain still because static friction has been demonstrated to be able to provide more force than the 200 N required to cancel your efforts. (D) (Static) friction is still the culprit, but because you are only providing 200 N, (E) friction is providing a force of only 200 N, opposite to the direction you're pushing in. Note that the force of static friction varies, depending on how much other force is being applied to an object at rest. It will always try to cancel out other forces applied to that object. There is of course a maximum to the force that static friction can provide. If an external force exceeds this maximum, the object will begin to move. Note that the force of static friction will never be greater than the sum of all other forces on the object (i.e. friction will never cause an object to start moving!).

12. Discouraged from your experience in Problem 11, you find a smaller crate, also on a level surface, that you *can* push. You begin pushing on it. You push harder and harder. Suddenly, it begins to move and you find that to keep it moving at a constant velocity, you don't have to push as hard on it as you did to start it moving. Why is this so?

    Answer: The maximum force that *static friction* (the frictional force that acts on objects at rest) can provide is larger than the force provided by *dynamic friction* (the frictional force that acts on objects that are moving). So when you are pushing on the crate at rest, you have to overcome static friction (you have to provide at least as much force as it is capable of). Once you do, the crate will start moving. To keep it at constant velocity (i.e. F_{net}=0), you only have to counter the smaller force of dynamic friction.

13. If the net force on an object is suddenly tripled, (A) will the magnitude of its acceleration increase or decrease and (B) by how much? If the mass of a block accelerating horizontally across the floor were to somehow triple suddenly while the net force remained constant, (C) would its acceleration increase or decrease and (B) by how much (assume the net force acting on it does not change)?

    Answer: (A) The magnitude of its acceleration will increase by (B) a factor of three. This is because acceleration is directionally proportional to net force. We can see this from Newton's Second Law. If we call a_1 the original acceleration, a_2 the new acceleration, m the mass, and F_{net} the original net force acting on the object, then we have to begin with:

    $$a_1 = \frac{1}{m}\ F_{net}$$

    If we now triple the original force to find the new acceleration, we see that the new acceleration is three times as large as the original:

    $$a_2 = \frac{1}{m}\ 3F_{net} = 3a_1$$

    (C) Assuming the net force does not change, then tripling the mass would decrease the acceleration (D) by a factor of three:

    $$a_1 = \frac{1}{m}\ F_{net}$$
    $$a_2 = \frac{1}{3m}\ F_{net} = \frac{1}{3}a_1$$

14. (A) Why does a heavy parachutist fall faster than a light parachutist if they are using identical parachutes? (B) Does this contradict Galileo's finding that objects fall at the same speed regardless of mass?

    Answer: When parachutists are falling, they are falling at their terminal velocity, which is reached when the force of air drag is equal (but opposite) to the force of gravity. The lighter parachutist has a smaller force of gravity pulling her down, so she needs less air drag to be at her terminal velocity than the heavier parachutist. The force of air drag is determined by two things: (1) the "frontal are" of the falling object and (2) the speed of the object. The bigger the "frontal area", the bigger drag force. The higher the speed, the bigger the drag force. In the cases of parachutists, the "frontal area" is determined by the size of the parachute. Since both the heavy and light parachutist are using identical chutes in this case, they have the same "frontal areas." So the only way for the heavier parachutist to get a larger drag force to cancel his larger gravitational force is to fall faster.

15. (A) What contains more apples: a 1 lb bag of apples on Earth, or a 1 lb bag of apples on the Moon? (B) What contains more apples: a 1 kg bag of apples on Earth, or a 1 kg bag of apples on the Moon?

    Answer: (A) A 1 lb bag of apples on the Moon contains more apples. Remember, the unit of pounds (lb) is a measurement of *weight*. Weight is defined as:

    $$weight \;=\; (mass\ of\ something) \times (acceleration\ due\ to\ gravity)$$

    The acceleration due to gravity on the Moon is significantly less than on Earth, so for two bags of apples to have the same weight, the bag on the moon must have more mass– in this case, more apples[1]! (B) Both bags have the same number of apples. Remember that the kilogram (kg) is a measure of mass, so if the two bags have the same mass, they have the same number of apples.

16. While in an orbiting space shuttle, you are handed two identical boxes, one filled with sand and the other filled with feathers. How can you determine which is which without opening the boxes?

    Answer: In an orbiting space shuttle, there is plenty of gravity, but because everything is falling at the same rate (falling around the Earth = orbiting the Earth), it is as though everything were weightless. Therefore, you cannot simply lift the boxes to determine which one is which– in other words, weight is not an option. You can, however, push on them and see which one is easier to accelerate. The one that is easier to accelerate has the lower mass and must be the feathers ($F = m\,a$, so a lower mass means higher acceleration for the same force).

17. You and a friend are trying to push a crate across a flat floor. The crate is too small for both of you to push on it from one side, but it is heavy so it isn't quite possible for just one of you to push it due to friction. You play rock-paper-scissors and determine that your friend will be the unlucky one to push the crate. Your friend suggest that you get in the front and pull up on the crate. Even though it's too heavy for you to lift off of the floor, why would this help? (Don't ask me why he doesn't ask you to *pull* on the crate...).

    Answer: The force of friction is what is causing the problem. Although you can't get alongside your friend to push the crate, you could get on the other side and lift up on the crate. Even though you may not be strong enough to lift the crate off the ground, you can reduce the effective weight of the crate and reduce the force of friction that way.

18. What is the greatest acceleration a runner can muster if the friction between her shoes and pavement provides a force equal to 75% of her weight?

    Answer: We need to consider the net horizontal force acting on the runner. In this case, it will be equivalent to the frictional force (why?), if we assume that air drag is too small to worry about. From the problem we know that this force is equal to 75% of her body weight. Her body weight is equal to her mass times the acceleration of gravity. Therefore, the net horizontal force, $F_{net,H} = 0.75\ mg$. Newton's Second Law tells us:

    $$F_{net,H} = 0.75\ mg = ma$$

    Solving for a by dividing each side by m, we find:

    $$a = 0.75\ g = 7.5`m/s^2$$

[1] I am, of course, assuming that the mass of a Moon apple is the same as an Earth apple!