Questions before Exam 1

1. **How does physics relate to microbiology?**

   In many ways, but the most obvious to you, as students just learning about forces now, would be how the forces in a microscopic, liquid environment are very different from the forces in our everyday experience. For example, motion in liquids is dominated by the drag force. And in dense liquids, a good approximate model for drag has it proportional to v, not v^2 as in air resistance. In other words, the magnitude $D = cv$ (where c is a complicated constant depending on details of the object and the liquid) and direction opposite to $\vec{v}$. This results in a world where, where $\sum \vec{F}$ stands for the sum of forces other than drag, it looks not like $\sum \vec{F} \propto \vec{a}$ but instead $\sum \vec{F} \propto \vec{v}$.

   Question I could ask: If the drag force is $\vec{D} = -c\vec{v}$, would an object with weight mg falling down in a liquid environment still attain a terminal speed, just as in air? If you think it will, derive an equation for v_T in liquid in terms of c, m, and g. Otherwise, if you think it won't, draw a rough graph of v vs t for an object falling in liquid, starting from rest.

2. **Is there a drastic change in air resistance or other forces once you break the sound barrier?**

   No. Moving to a speed greater than that of sound is interesting, and you will be able to learn more about it when we deal with sound and waves early in the second semester. But the processes behind drag, such as turbulence, are not different above the speed of sound in any way that would matter at the very basic level of analysis we do in an introductory physics course.

   Question I could ask: Is there something like a terminal speed in the *forward* direction for a jet plane traveling through the air? That is, is there a v_{max} due to the drag force that an airplane cannot exceed, no matter how high the thrust force propelling it in the forward direction?

3. **Is there a terminal speed unique to an object? Or can something have multiple terminal speeds?**

   The drag force in air, and hence the terminal speed, depends on C_D and A, which in turn depends on what side of the object is facing downward as it falls. Therefore a single object can have multiple terminal speeds.

   Question I could ask: You drop two identical glasses, starting from rest, at the same time, from the top of a tall building. You release one of the glasses bottom-side down, the other the bottom-side up. (a) If you could drop them such that they didn't tumble, which glass would reach the ground sooner? Explain. (b) The bottom-side up glass will be unstable as it falls, and it will start to tumble. Does this change your answer?

4. **How would the altitude and range of a hot air balloon depend on its size?**

   We need a couple of more forces to add to our catalog of forces before we can really deal with hot air balloons, particularly the buoyancy force which we will encounter at the end of the semester. But let's say we could control the altitude as we liked. Among the forces we have encountered so far, the one that would be most affected by the change in altitude would be the drag force. The air pressure decreases with altitude, so that the balloon would tend to expand. This affects the drag force. The density of air also decreases with altitude, which also affects the drag force.

   Question I could ask: As a hot air balloon rises, does the drag force on it at a given speed v become (a) larger, (b) smaller, or (c) you have insufficient information.

5. **What forces keep vining plants from falling down?**

   Vines support themselves by adhering to more rigid structures. If we were to approach vines in our so far rather limited physical vocabulary of forces, what would stand out would be the vines' own weight as a very significant force for them. Their weight needs support, and they attach themselves to vertical surfaces by what looks very much like strings, with tension forces. A coiled vine looks like a spring, which would collapse under its own weight if it weren't held up.

Question I could ask: In your lab with springs, you had the equation $T^2 = [(2\pi)^2/k]\, m$. But you will have noticed that in your T^2 vs m graph, the straight line didn't pass through the origin: with $m = 0$, $T^2 > 0$. Remembering that your spring was not massless, can you explain why?

6. **Why can we get broken bones but not muscles or skin shattered?**

   This has to do with the elastic properties of different materials. Forces on more rigid materials such as bones cause them to flex a little, but larger and larger forces eventually exceed a limit beyond which the material deforms and even breaks. They are like very-high k (very stiff) springs that give large forces with small Δx in $F = k\Delta x$. Springs in the lab can get permanently deformed when they are stretched too much; with large k, it does not take a large Δx to reach large forces. More elastic materials such as muscles and skin are like springs with small k (not stiff), so they can stretched a lot more (large Δx) before permanent deformation sets in.

   Question I could ask: In the centripetal motion lab, there were two different types of spring I handed lab groups: a stiff spring with a larger k_l and a less stiff one with smaller k_s; $k_s < k_l$. The initial, unstretched lengths of both types of spring were the same. If one lab group had a spring with k_l and one with k_s, and they both had equal masses m going around in a equal sized circle with radius r, which group's mass would be rotating faster? Provide an argument that uses the appropriate equations to show that $v_l > vs$ or $v_l < vs$.

7. **How is physics related to the human body?**

   Everything is physics. But at an introductory level, where we consider basic forces, a biomechanical model of the human body is the most obvious application of physics to the body. We have a rigid structure provided by the skeleton, with bones linked together by joints that constrain rotation, and by muscles and tendons that act roughly like springs. So we can identify forces, deal with the geometry, and use $\sum \vec{F} = m\vec{a}$ (and its rotational analogue we'll see in a few weeks) for all the various bones. But at this point, a pencil-and-paper calculation will no longer be feasible; we have to depend on computerized models.

Question I could ask: Consider a joint, such as your wrist, where two bones come together. Is friction a force that you need to account for when modeling a wrist joint? Do you think the joint has mechanisms, such as lubrication, to minimize friction, or does it not matter much?

8. **What is the physics relevant to Olympic swimmers or athletes?**

   Much of the physics concerning athletes is beyond us now: we at least need some concepts of energy and thermodynamics that we will not see until the end of the semester. But there are some example we can discuss; for example, how athletes often take measures to reduce friction and drag. When differences of hundredths of a second are at stake, even very small advantages can matter, so that elite racers' clothes and equipment are designed to reduce friction and drag as much as possible. A couple of Olympics ago many swimmers started competing in full-body suits, made of special materials that reduced friction with water, and also slightly increased buoyancy to lift the swimmer out of the water to have less contact with the higher-drag environment of water, a much denser fluid than air. So new rules regulating swimwear had to be put in place.

   Question I could ask: You have an object with mass m moving on a flat surface, released with initial velocity v_i. The coefficient of kinetic friction between the surface and the mass is μ_k. You also have a second object which is released with the same initial velocity v_i. This second object is placed in a sleeve that reduces friction by 1%, so that its coefficient of kinetic friction with the surface is $0.99\mu_k$, but increases its total mass by 1%, so that its mass is $1.01m$. Which object will travel a larger distance before coming to a halt?

9. **Could you start a fire by rubbing hands together?**

   Sort of. You will, toward the end of the semester, be able to understand how fast you must rub your hands together to heat your hand beyond a temperature where they would combust. (Actually being able to do it is another matter. Severe discomfort and tissue damage, at any rate, is easy enough.) It's hard now, where you don't yet have concepts of heat and work, only forces. But still, you might notice a connection between friction and heat. We will learn more in the coming weeks.

Question I could ask: What kind of friction helps you walk across the floor: static or kinetic? Explain.

10. **How much would you have to reduce air resistance, friction, drag, etc for perpetual motion? Would magnetism do it?**

    Perpetual motion is impossible for objects that are more than just a few atoms in size. We will see a bit more about this when we start dealing with thermodynamics, but for now, we can look at some of the difficulties involved with the forces. First of all, the problem arises from some nuisance forces called "nonconservative forces," most prominently friction and drag. You can reduce friction between moving parts with lubrication, advanced materials, even by eliminating direct contact by magnetic means. But none of this will give you $\mu_k = 0$ exactly. You can reduce drag by operating in lower and lower air density and pressure, but not even outer space is as perfect a vacuum as you would need.

    Question I could ask: You might think of friction of a nuisance, but we also depend on it. Give two examples of everyday processes that would be impossible without friction.

11. **If ta semi truck with a large mass collides with a smart car with a small mass, can we calculate at what velocity the smart car must have in order for the crumpled vehicles to both come to complete stop?**

    Yes, this is a classic collision problem, which we will deal with both in the lab and in class when we deal with momentum and energy. In fact, you will very easily be able to solve this sort of problem. For now, just notice that if you were to approach this problem by trying to calculate the accelerations using $\sum \vec{F} = m\vec{a}$, it would be impossible. Crumpling involves complicated forces rapidly varying in space and time; you are not mathematically equipped to handle anything but constant acceleration. Even if you were, you would still need a very sophisticated computer model. And yet, I am promising you that you will be able to do this problem very easily.

    Question I could ask: During the collision of the truck and the car, what is the relationship between the total force on the car due to the truck, and the total force on the truck due to the car? More force on the car? On the truck? Equal? What about the acceleration magnitudes? More acceleration by the car? The truck? Equal?

12. **Rail gun vs. coil gun?**

    We're not equipped to deal with such guns yet: we have to wait until the second semester to add forces due to electric and magnetic interactions to our catalog of forces.

    Question I could ask: You have two magnets interacting, and you realize that the magnitude of the force between them depends on the distance between them. So you want to be able to measure and plot the magnetic force magnitudes at various distances. Say I give you two magnetized carts on a low friction track (we will do this in the lab in a week or two) Devise a way to measure the force between them at various distances, using equipment you have been using in the labs you have done do far.

13. **Higgs boson?**

    You will be able to understand more about this toward the end of the second semester, when you will know a bit more about elementary particles and fundamental forces. Very basically, however, interaction with the Higgs field is the mechanism proposed for particles like electrons to acquire mass. Zero-mass particles (such as photons, which are light particles) sound odd, but it turns out that particles not having zero mass is what calls for an explanation.

    Question I could ask: Say you have a zero mass particle, like a photon. What does $\sum \vec{F} = m\vec{a}$ tell you about how a photon will respond to a total force on it? (The result should be hard to make sense of. This is your first intimation that in a world that contains $m = 0$ particles, the basic Newtonian physics we are learning now will not be enough.)

14. **Why does the Moon not fall to the Earth and the Earth not fall into the Sun?**

    The Earth and the Moon are gravitationally attracted to one another. That means that they exert forces on each other that are in the direction of themselves. And since in outer space, the only relevant force to consider between the Earth and Moon is gravity, that means that the Earth and Moon must be accelerating toward one another, and must have been doing so for billions of years. But that is not a problem. The direction of $\vec{a}$ is not the same thing as the direction of $\vec{v}$! In a uniform circular orbit, the revolving object will have $\vec{a}$ directed toward the center of the circle, and a tangential $\vec{v}$, with $\vec{v} \perp \vec{a}$. Without outside interference, this can go on indefinitely, with the revolving object never getting any closer to the center of the circle.

Question I could ask: Give two everyday examples of motion where the direction of $\vec{v}$ is different from that of $\vec{a}$.

15. **How would a shrink ray work?**

    It wouldn't. The best option might be a device that thoroughly scans the structure of an object, destroying it in the process, and then replicates the same structure at a smaller scale using the same materials, using something like a super-advanced 3D printer. This has limits: at some point, once you start approaching molecular-scale miniaturization, you simply can't ignore the granularity and have near-exact replication of structures. In electronics, for example, we are starting to get to limits of miniaturization this way.

    Question I could ask: Consider an experiment we did in the lab, where you mostly understand the forces in play. Say you shrunk it down to 1/1000 its size. Would the relative importance of various forces in play stay the same, so you do essentially the same experiment?

16. **Superhuman strength—lifting cars in an emergency?**

    It's not exactly clear that such events happen—none of them have been documented in such a way that we can be sure that the story happened exactly as told. You may want to look up some more skeptical sources before thinking about the physics behind stories that may well have been exaggerated.

    Question I could ask: You hear a story that apparently violates your understanding of physics. It's possible that it did really happen; after all, your knowledge of physics is always incomplete. But then again, maybe it didn't happen; if it seems to violate well-understood physics, that may be a good sign that somebody has made a mistake. How do you decide?