

1. (20 pts) Two ladybugs are sitting on a rotating turntable and are going around without slipping. Both bugs have the same mass, but bug B is twice as far from the center as bug A. Use the coordinate system shown: the turntable is rotating about the z-axis and the x- and y-axes are in the plane of the disk. The axes cross at the zeroes of their variables. (The coordinate system does NOT rotate.) At time $t = 0$, both bugs lie on the x-axis.

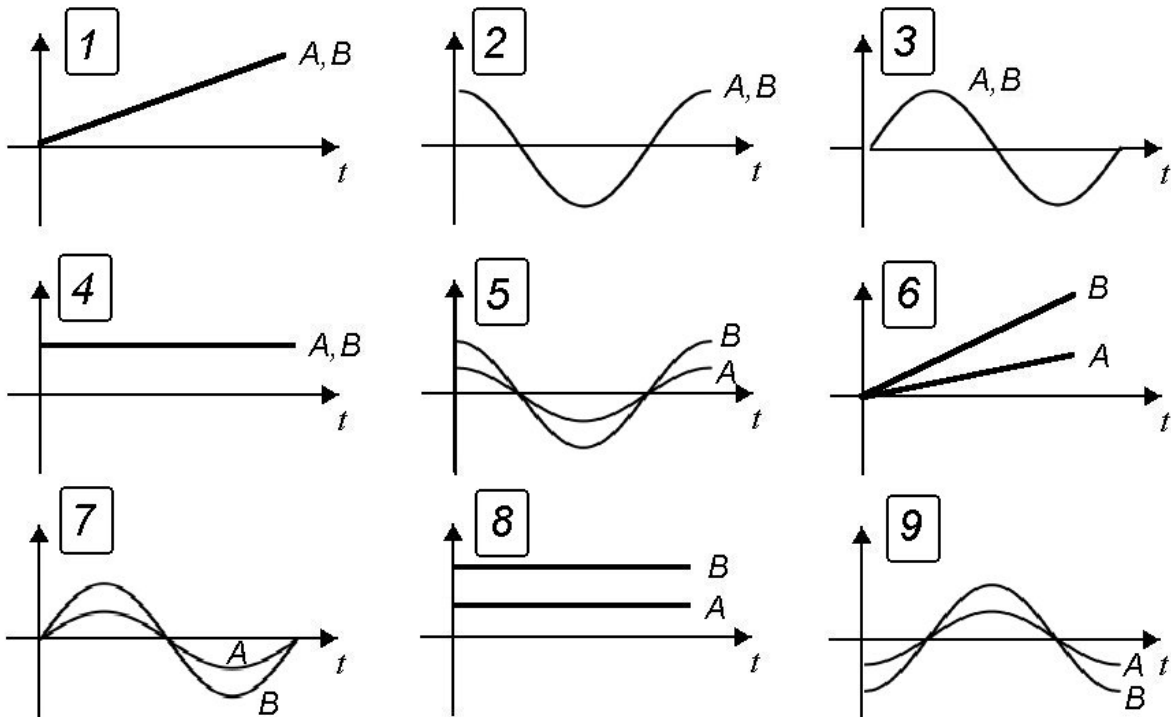
For the four physical variables below, identify which of the graphs in the figure below could represent that variable for both of the bugs if the scales on the axes were correct and put the number of the graph in the appropriate box on your answer sheet. The axes cross at the zeroes of their variables. (When only one line is shown, both bugs have identical graphs for that variable.)

1.1 The x-component of the friction force on the bugs;

1.2 The speed of the bugs;

1.3 The y-component of the velocity of the bugs;

1.4 The angular velocity of the bugs.



1. (30 points) An ideal gas is contained in an airtight box. Complete each of the following five statements below to show the quantitative change that will occur. For example, if you want to say that the volume, initially equal to V , quadruples, complete the statement with " $4V$ ".

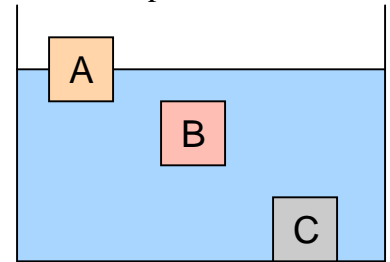
- If the absolute temperature of the gas is halved, the average speed of a gas molecule, v_0 , becomes _____.
- If the average speed of a gas molecule doubles, the pressure, p , on a wall of the box becomes _____.

- c. If the absolute temperature of the gas is halved, the pressure, p , on a wall of the box becomes _____.
- d. If the number of molecules in the box is doubled but the absolute temperature of the gas is kept the same, the average speed of a gas molecule, v_0 , becomes _____.
- e. If the number of gas molecules inside the box is doubled, but the temperature is kept the same, the pressure, p , on the wall of the box becomes _____.

II. (25 points) Suppose we mix 40 g of water at 90 °C with 30 g of water at 10 °C.

- a. What will be the final temperature of the mixture? (10 pts)
- b. How much heat does each gram of hot water lose?
How much does the temperature of each gram of hot water change?
How much does the temperature of the entire sample of hot water change?
(5 pts)
- c. How much heat does each gram of cold water gain?
How much does the temperature of each gram of cold water change?
How much does the temperature of the entire sample of cold water change?
(5 pts)
- d. Are your results to the first part of b) and the first part of c) the same or different? Explain why.
(5 pts)

2. (20 points) Three blocks are at rest in a tank of water in the positions shown. Each block has the same shape and size but they are made of different materials. Block A floats with part of its volume out of the water, block B can remain where it is shown, halfway down in the tank, and block C rests on the bottom. For each of the following four items, rank the quantity for the three blocks. For example, if the item were “volume”, since the volume of the blocks are the same, you would write “A=B=C.” If the item were “depth”, you would write “C > B > A”, since C has the largest depth, A the smallest, and B is in between.



- 2.1** Force pushing downward on the top of the blocks.
- 2.2** Force pushing upward on the bottom of the blocks.
- 2.3** Buoyant force the water exerts on the blocks.
- 2.4** Net force experienced by the blocks.

3. (20 pts) For each of the items below complete the sentence with quantitative words in the box on your answer sheet. Use words such as “not change”, “double”, “triple”, “halve”, etc. If you prefer, you may write, =, X2, X4, ÷2, ÷3, to mean equal, doubled, quadruples, halved, divided by three, etc. (Note that “increases” or “decreases” is NOT sufficient.)

3.1 The interior of a water pipe bringing water into your hot water heater has narrowed as a result of the buildup of scale from the fact that your water is very hard (contains dissolved chemicals). The radius of the open area inside the pipe has decreased by a factor of two. If the pressure differential remains the same, the flow into the heater will _____.

3.2 You have a single window in the wall of your kitchen and you are contemplating putting a second identical window into that wall. In the winter, for a given inside-outside temperature difference, that change will _____ the flow of heat out of your house through the windows in that wall.

3.3 Blood is flowing through an artery that has a partial blockage in a part of the artery so that half its cross sectional area is blocked. In the part with the blockage, the velocity of the blood is _____ the velocity of the blood in the unblocked part of the artery.

3.4 I blow as hard as I can through a single straw. If instead, I blow as hard as I can through two straws (of the same length as the single straw) placed side by side, the rate of flow will _____.

5. (10 pts) For the partial statements below choose the letters of the phrases that complete the statements correctly. If more than one is correct, give them all. If none is correct, write N.

5.1 A news station shows a video of an astronaut in a space station. She is demonstrating a tool that she used to make a repair to the station during a spacewalk. When she releases the tool it floats in the air next to her. The reason it does this is:

- A. There is no gravity in the space station.
- B. The tool and the astronaut are both in free fall.
- C. The gravity of the astronaut cancels the gravity of the earth on the tool.
- D. The net force on the tool is zero.
- E. They are both moving at the same high velocity.

5.2 In Star Wars IV, Luke Skywalker is seen dropping an object on the planet Tatooine. If the video is analyzed to determine the acceleration of the falling object, one discovers that $g = 9.80 \text{ m/s}^2$, the same as one would find on earth. However, the radius of Tatooine is approximately twice that of the earth. A plausible justification that $g_{\text{Tatooine}} \approx g_{\text{Earth}}$ is

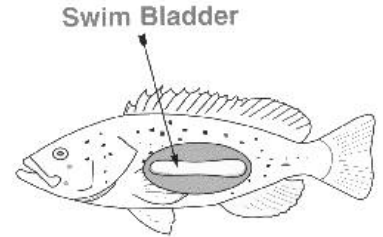
- A. The value of g is a constant in all situations.
- B. Tatooine has 2 suns and 3 moons.
- C. The mass of Tatooine is four times that of earth and cancels the effect of the larger radius.
- D. Luke is using his Jedi powers to alter the value of g .
- E. The movie was outsourced and actually filmed in Bollywood (Mumbai, India)

6.3 What is the weight of an object of mass m at the surface of a planet that has half the Earth's radius and half the Earth's mass? ($g = 9.8 \text{ N/kg}$)

- A. $\frac{1}{4} mg$
- B. $\frac{1}{2} mg$
- C. mg
- D. $2 mg$
- E. $4 mg$
- F. Something else.

I. (25 points) You may take $g = 10 \text{ N/kg}$ for this problem.

(a) Fish can adjust their buoyancy. They change their volume without changing their mass by inflating or deflating a balloon-like internal organ called a swim bladder with gas from chemical reactions.



In an estuary (the boundary between a fresh-water river and the salt-water ocean) the density of water in a particular region can change as the tide goes in and out and the mix between the less dense fresh water and the more dense seawater changes.

If a fish of mass 3000 g can float just above the bottom of a volume of estuarine water (density $\rho = 1.05 \text{ g/cm}^3$), by how much does it need to change its volume to stay where it is if the density of the water changes to $\rho = 1.060 \text{ g/cm}^3$? Explain your reasoning. (15 pts)

(b) If you are lying down and stand up quickly, you can get dizzy or feel faint. This is because the blood vessels don't have time to expand to compensate for the blood pressure drop. If your brain is 0.4 m higher than your heart when you are standing, how much lower is your blood pressure at your brain than it is at your heart? The density of blood plasma is about 1025 kg/m^3 and a typical maximum (systolic) pressure of the blood at the heart is 120 mg of Hg ($= 16 \text{ kPa} = 1.6 \times 10^5 \text{ N/m}^2$). (10 pts)

I. (20 points) Some of the recent exciting information about the cosmos we live in come from orbiting telescopes, but other important information comes from (much less expensive) high flying balloons.

A) Scientific balloons usually use at least some Helium to provide lift. Suppose that Helium has a density ρ_{He} while air has a density ρ_{air} . (These both depend on circumstances, but suppose these numbers are given.) Suppose the balloon is filled with Helium until its volume expands to an amount V . If the balloon has a payload (mass of the balloon's skin, scientific instruments, and parachute) of mass m , what volume does the balloon need to be filled with in order to start it rising? You may assume that the balloon is entirely filled with helium (no air mixed in) and you may ignore the volume of the payload compared to the volume of the balloon. Express your answer in terms of the given parameters and any physical constants you might need.



B) The density of helium at normal air pressure is about 0.2 kg/m^3 and the payload of a typical scientific balloon is about 4000 kg. To what volume should the balloon be inflated with helium in order to get it off the ground? (The density of air is given in the table at the beginning of the test.) (5 pts)

III. (15 points) Estimate the number of trees growing within 100 feet of the Washington Beltway. Be sure to clearly state your assumptions and how you came to the numbers you estimated, since grading on this problem will be mostly based on your reasoning, not on your answer. We are not

interested in whether you can “guess” a right answer, but in whether you can use your everyday experience to infer information about topics about which you may have little direct knowledge.

III. (15 points) If you drink cold water it will soon warm up to body temperature (about 37 °C). This takes energy. Therefore, you ought to be able to keep your weight down even if you eat fattening food provided you also drink lots of cold water. Estimate what volume of cold water you would need to drink to overcome the effect of eating one chocolate sundae (about 500 Cal). *Be sure to clearly state your assumptions and how you came to the numbers you estimated, since grading on this problem will be mostly based on your reasoning, not on your answer..*

III. (15 points) Two schoolmates, Romeo and Juliet, catch each other's eye across a crowded dance floor at a school dance. Estimate the gravitational attraction they exert on each other. (Hint: $G \sim 2/3 \times 10^{-10} \text{ N}\cdot\text{m}^2/\text{kg}^2$.) *Be sure to clearly state your assumptions and how you came to the numbers you estimated, since grading on this problem will be mostly based on your reasoning, not on your answer.*

IV. (10 points) Throughout this class we have focused on making the connection between physics and everyday experience. One result was that we used a small number of equations but tried to “see the dog” in every equation, that is, make physical sense of it. Choose one equation that we used in this class, state it mathematically and explain what each symbol or term in the equation means. Then explain briefly (as if to a confused student in the class) what is “the dog” in the equation you have chosen. *Note: This is an essay question. Your answer will be judged not solely on its correctness, but for its depth, coherence, and clarity.*

IV. (15 points) In class, we discussed a number of concepts relating to the sense of hot and cold: temperature, thermal energy, and heat flow among them. We made an attempt to both connect to our personal experience of heat and cold and to reconcile our senses with a consistent scientific picture. Discuss one apparent sensory conflict and how it can be resolved with a consistent scientific picture. If you did not have a conflict yourself, discuss one expressed by someone in class or a plausible one that your roommate might have. *Note: This is an essay question. Your answer will be judged not solely on its correctness, but for its depth, coherence, and clarity.*

Extra Credit (5 points): Have you learned anything in this class that you think will be of any use to you in five years? If so, what? If not, why not? Any thoughtful answer will receive full extra credit points. (Don't do this until you have completely finished the rest of the exam.)