(25 points) Using a rope of negligible mass, a box is pulled along a horizontal surface as shown in the figure below. Initially, the marker arrow on the box points to the position marked 0 and the box is at rest. At time $t = 0$ a tension force T_0 is exerted on the box and the box begins to move. The tension force stays constant until the arrow marker on the box reaches the point marked A at a time $t = t_1$. At that point the force changes to a new constant value of T and the box continues to move with a constant velocity until it passes position B at a time $t = t_2$. The force of friction f cannot be neglected. Use a horizontal coordinate system centered at 0 with the +x direction pointing to the right. If you need g, use the value of 10 N/kg.
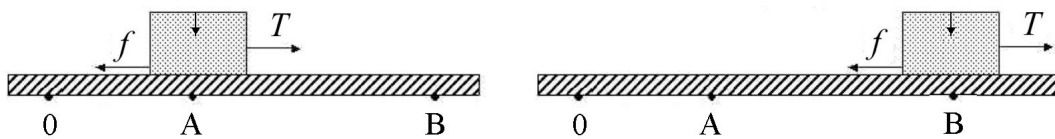
A. In the space below, draw a free-body diagram showing all the forces acting on the box at a time between the times $t = t_1$ and $t = t_2$. Be sure to identify the type of force and what object is causing it. (5 pts)

B. The box has a mass of 2 kg, and the coefficient of sliding friction between the block and the table is 0.25. The box has attained a speed of 0.3 m/s when it reaches point A. Find the tension force, T, if you can, and explain how you know what it is. If you cannot find it, explain what additional information you would need to find it. (5 pts)

$$T =$$

C. If the distance between A and B is 0.7 m, find the work done by the tension and friction forces as the box moves between points A and B. Show your reasoning. (7 pts)

$$W_T =$$
$$W_f =$$

D. Find the impulse delivered to the box by the tension and friction forces as the box moves between points A and B. Show your reasoning. (8 pts)
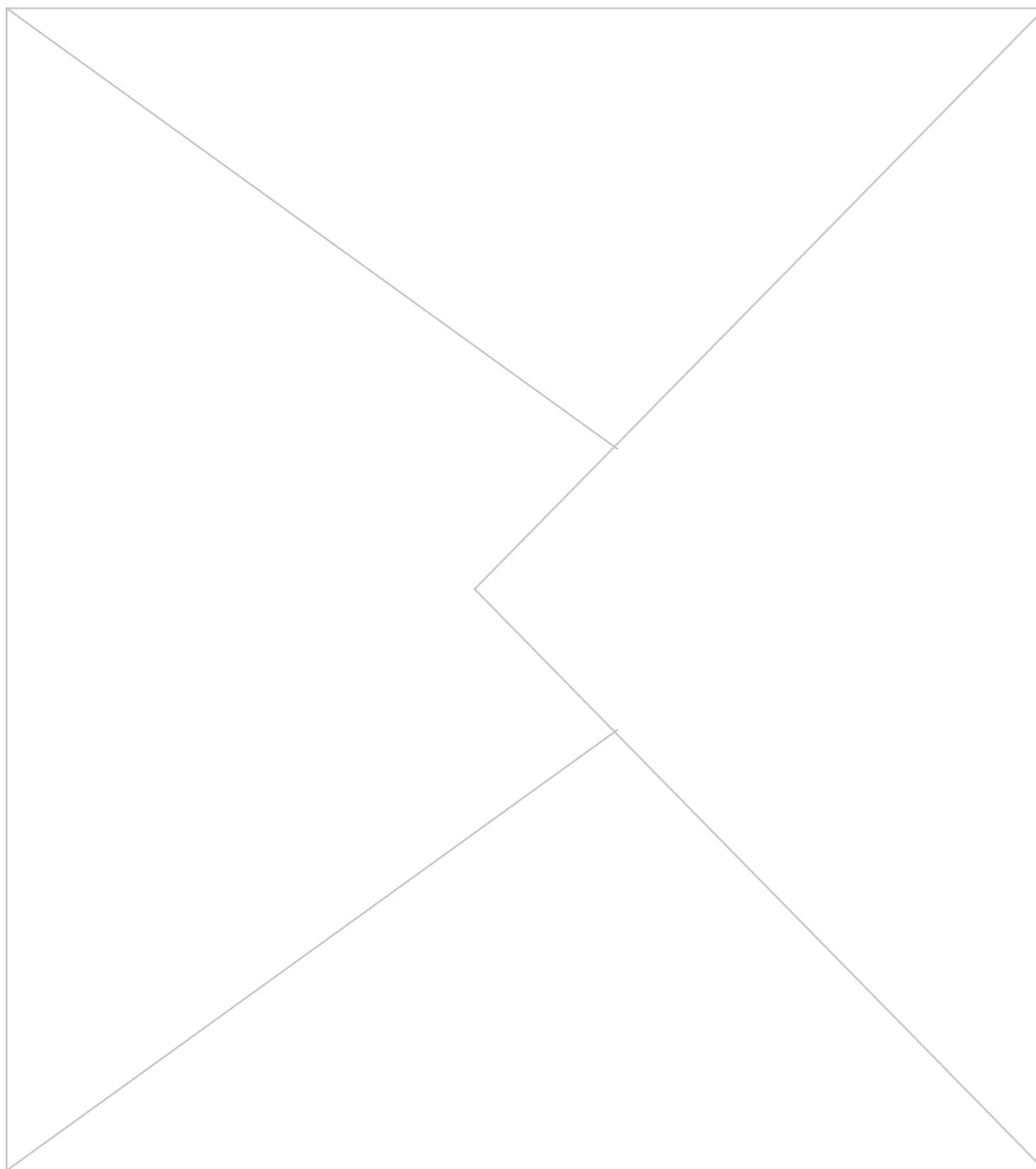
$$\mathscr{I}_T =$$
$$\mathscr{I}_f =$$

(15 points) The water company that provides water to houses in the
DC area (WSSC) charges both for providing water and for carrying waste
water away. The combined rate is about 1 cent per gallon. My niece, the
environmentalist, chides me not to run water when I am brushing my teeth.
Estimate the cost to me in one year if I let the water in the sink run while I brush my teeth.
*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.*

If you need more space, continue on the back and check here.

(10 points) Three physics students had different answers to the following quiz problem:

> *A spring-loaded toy dart gun is used to shoot a dart straight up in the air, and the dart reaches a maximum height of 24 m. The same dart is shot straight up a second time from the same gun, but this time the spring is compressed only half as far before firing. How far up does the dart go this time, neglecting friction and air resistance and assuming an ideal spring?*

Fred said, "I don't think it will make any difference." Ethel said, "No, Fred. It will go half as high." Lucy said, "I think it will only go ¼ as high." Who is right and suggest how the one who is correct might convince the other two? (Just giving the answer in the louder voice is not good enough.) The one with the correct answer has to have a good physics reason. Explain that reasoning in a way that should be convincing to the others. *Note: This is an essay question. Your answer will be judged not solely on its correctness, but for its depth, coherence, and clarity.*

If you need more space, continue on the back and check here.

(25 points) In the three figures labeled A, B, and C at the right are shown three situations in which a bulldog on a skateboard traverses a dip in the ground. (The dips are all the same.)

In A, the bulldog enters the dip traveling at a non-0 kinetic energy (KE). In B, when he leaves the dip, he has 0 KE. In C, he begins in the dip (at the position indicated) at a KE of 0. Since he is riding a skateboard, friction may be ignored.
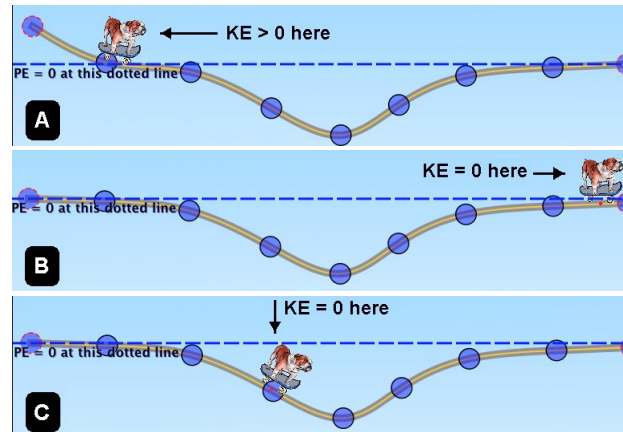
A. In the figures below are shown graphs of the KE, gravitational PE, and total energy as a function of <u>position</u>. In situation 1, the total energy is negative; in situation 2, the total energy is 0; and in situation 3, the total energy is positive. Match which situation goes with which graph and put the letter of the situation to the left of the corresponding graph. (6 pts)
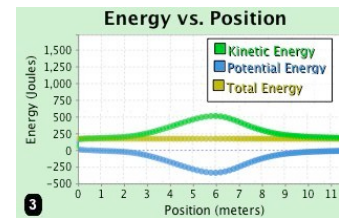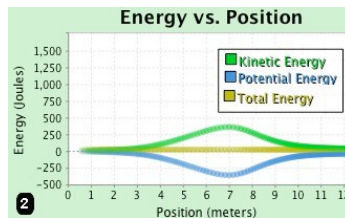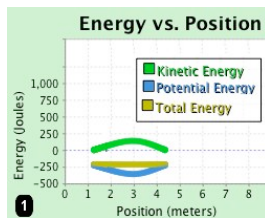
B. The bulldog and skateboard have a combined mass of 20 kg. In case B (the middle of the three pictures of the bulldog and the well), the bulldog and skateboard have a KE of 380 J when they roll past the bottom of the well. How deep is the well? (8 pts)

Depth =

C. In case 1 (the left one of the three graphs) it says the KE is positive but the total energy is negative. How is this possible? Explain what it means for the total energy to be negative. (5 pts)

D. In case 3, the total energy is 200 J. How fast is the bulldog when he passes the bottom of the well? (6 pts)

$v =$

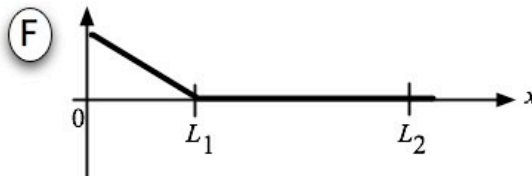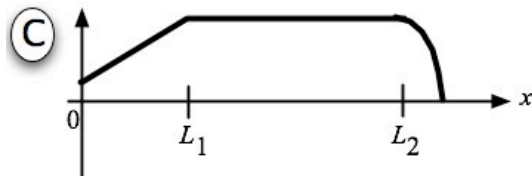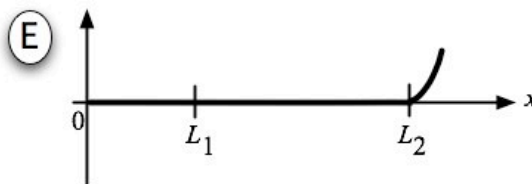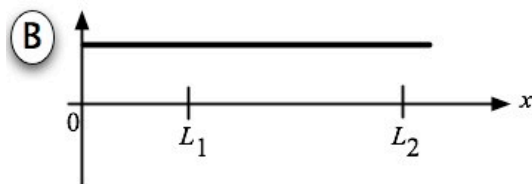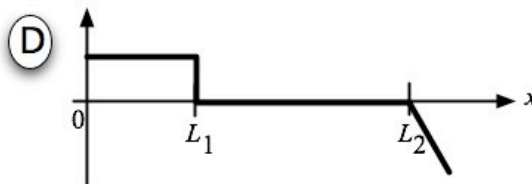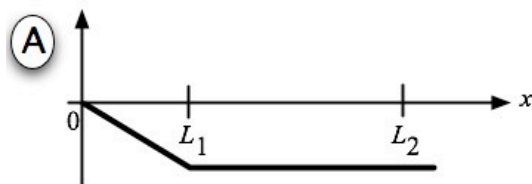If you need more space, continue on the back and check here.

(25 points) A toy train comes off a hill traveling at a velocity v_0, rolls down an incline of height h, rolls a short distance on a straight track, and strikes a bumper containing a spring, which is strong enough to stop the train. The distances are as indicated on the figure below. The train is just rolling, not powered.
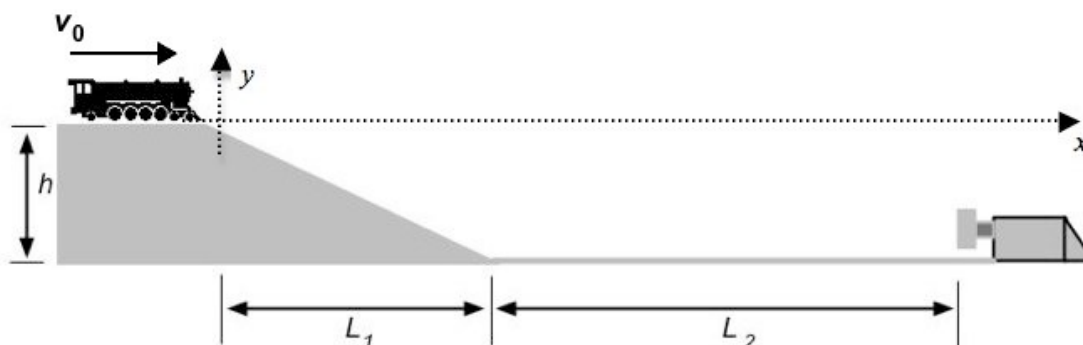
Which of the graphs below could represent the following variables of the system expressed *as a function of the position of the front end of the engine* using the coordinate system shown? For this problem, ignore friction. Put the letter of all graphs that would work for a given variable in the space provided. If none works, put N and sketch what it would look like.

_____ 1. The total mechanical energy of the system.

_____ 2. The potential energy of the spring.

_____ 3. The gravitational potential energy of the train.

_____ 4. The kinetic energy of the train.

_____ 5. The x-component of the net force on the train.

If you need more space, continue on the back and check here.

(15 points) Some people think that it is implausible that humans can be affecting the amount of CO_2 in the atmosphere because the atmosphere is so big and we are so small. The total mass of the atmosphere <u>is</u> very large – about 5×10^{18} kg. But CO_2 is a fairly small fraction of this – about 6×10^{-4} of its mass. According to the website on carbon footprints,[1] the average amount of CO_2 produced by a person in the US is about 20 metric tons per person per year. (One metric ton is 10^3 kg.) If every person in the world produced this much CO_2 every year, how long would it take to increase the amount of CO_2 in the atmosphere by 20%? (This is oversimplified, but gives us a reasonable idea of whether it is at all plausible that human produced CO_2 can be significant.)
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.

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[1] http://www.carbonfootprint.com/carbonfootprint.html
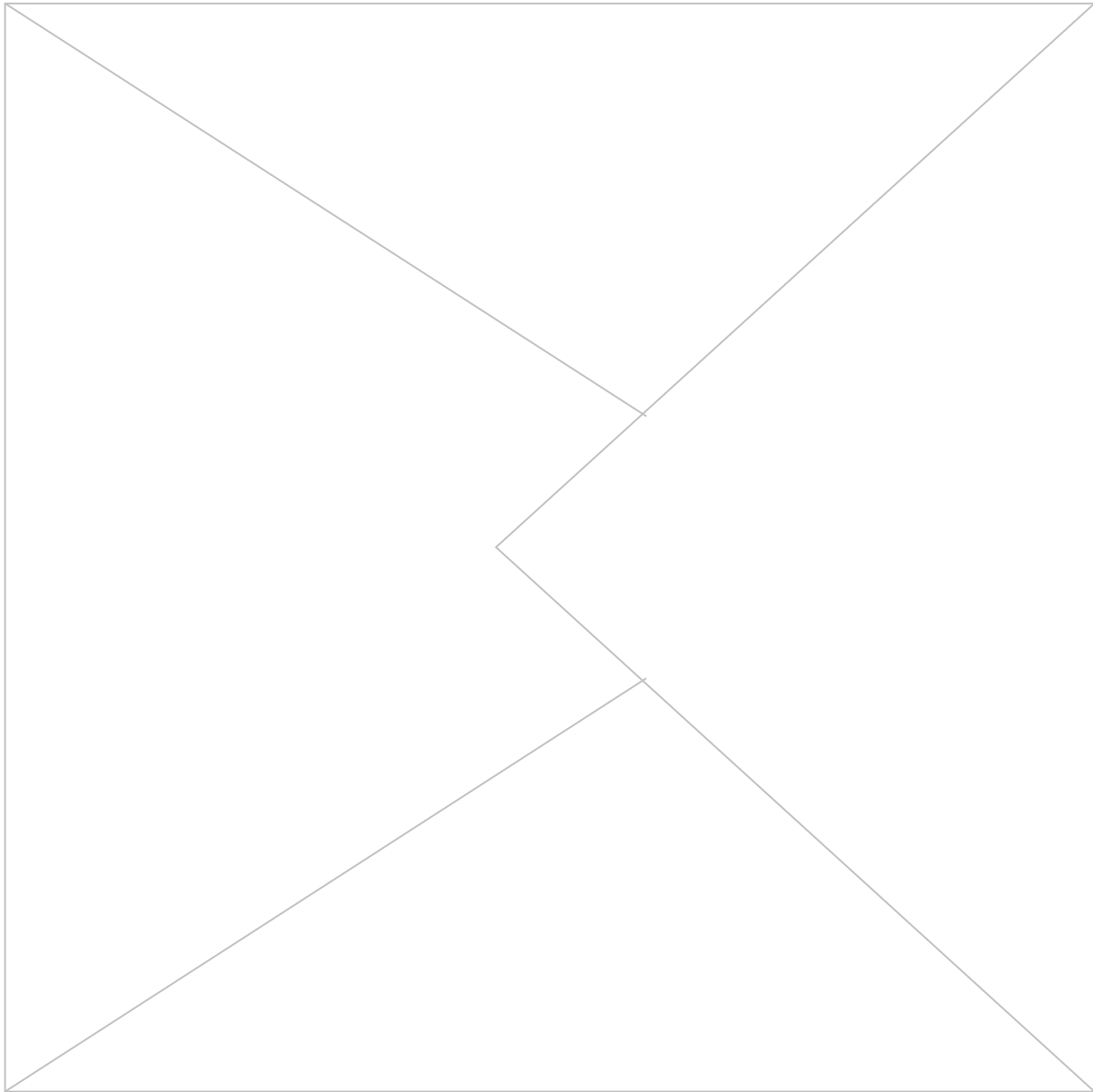
If you need more space, continue on the back and check here.

(10 points) In our discussion of the law of momentum conservation, we were careful to show its connection with the fundamental principles – the relevant Newton's laws. State the principle of momentum conservation and discuss whether you found the connection between it and Newton's laws helpful. Give reasons for your decision. *Note: This is an essay question. Your answer will be judged not solely on its correctness, but for its depth, coherence, and clarity.*

If you need more space, continue on the back and check here.

(25 points) A remarkable species of ants known as "trap-jaw ants" have a pair of jaws (mandibles) that can open to 180° and quickly snap shut, either to attack prey or in self defense. As a defense mechanism, snapping its jaws shut on the ground sends the ant flying off backwards or up into the air, to a distance many times the ant's length. The head of the ant with the jaws in the open and closed position are shown at the right.[2]
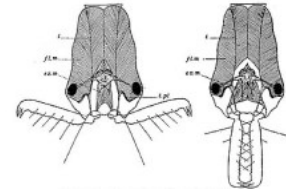
A group at Berkeley[3] took high-speed videos of the ants jumping. (The frame rate was one frame every 20 <u>micro</u>seconds – 2×10^{-5} s – about 1000 times faster than an everyday video!) From these videos, they were able to extract the position and velocity of the snapping mandibles, as shown in the graphs at the right. These are the data for "unobstructed" mandibles – ones that snap closed but don't hit anything. Let's use these data to get an idea of the forces involved.
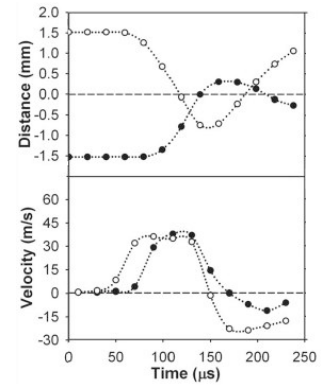
A. One mandible (the one represented by the open circles in the graphs) changes its speed from about 40 m/s (that is NOT a typo) to -30 m/s in about 40 μs (4×10^{-5} s). If the mass of the mandible is 130 μg (1.3×10^{-7} kg), find the momentum change of the mandible and the average force acting on it during that time. (10 pts)

$$\Delta p =$$

$$<F^{net}> =$$

B. If the force from the two mandibles is exerted on an object in front of the ant, the ant will be thrown backward or upwards. If the mass of the ant is 12 mg (1.2×10^{-2} kg), with what speed will the ant be thrown backwards? (10 pts)

$$v_0 =$$

C. If each mandible moves 2.0 mm while exerting its force on the ground about how high will the ant be thrown in the air? (Simplify the calculation by ignoring air resistance and assuming the ant is pushing straight down the entire time.) (5 pts)

$$h =$$

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[2] Wikipedia, *Odontomachus*, accessed 11/16/10.

[3] S. N. Patek et al., *Proceedings of the National Academy of Sciences***103**:34 (8/22/2006) 12787-12792

If you need more space, continue on the back and check here.

(20 points) The figure at the right shows **the full** free-body diagram for two cubical blocks of identical volume that are held underneath the surface of a tank of water.   The arrows represent the total force in each direction acting on the block. The labels on the arrows (U, D, L, and R) indicate the direction that the forces point (up, down, left, and right), <u>not</u> the side of the cube that is feeling the force. (The arrows on the faces at the front and back of the cube that point into and out of the page are not shown.)
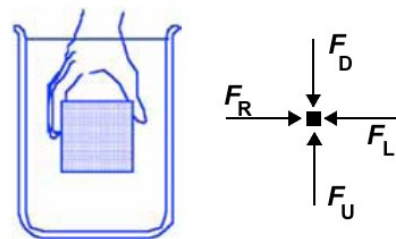
3.1. When block #1 is released, it will sink. Rank the magnitudes of the forces F_L, F_R, F_U, F_D just after the block is released. (6 pts)

3.2.   When block #2 is released, the block will float partially out of the water. Rank the magnitudes of the forces F_L, F_R, F_U, F_D just after the block is released (6 pts)

3.3. In which of the two cases is the buoyant force exerted by the water on the block greater? (4 pts)

> (a) For block #1.
> (b) For block #2.
> (c) They are the same.
> (d) You do not have enough information to decide.

3.4. In which of the two cases is the force exerted by the water on the <u>top</u> of the block greater? (4 pts)

> (a) For block #1.
> (b) For block #2.
> (c) They are the same.
> (d) You do not have enough information to decide.

(20 points) In class we blew through coffee straws configured in a variety of ways shown at the right. Complete each of the sentences below with a quantitative phrase, e.g., "=" for "the same as", X2 for "twice as much as", "X1/2" for "half as much as, etc.
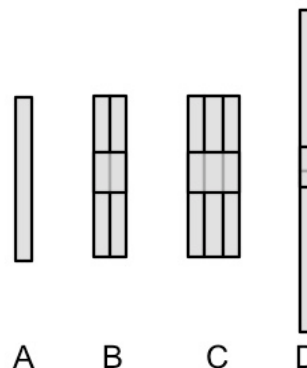
6.1. We should expect the flow rate through B to be _____ the rate through A.

6.2. We should expect the flow rate through C to be _____ the rate through B.

6.3. We should expect the flow rate through D to be _____ the rate through A.

6.4. The resistance of B in the H-P equation is _____ that of A.

If you need more space, continue on the back and check here.