Physics 231 – Lab 9
Energy & Momentum for a 'multi-particle' system (you)

Equipment: Force Plate, Motion Sensor mounted on high rod

Objectives

The goal is for you to have a side-by-side comparison of how different analytical approaches can be used analyze a system, even provide alternative paths to the same final answer. You will analyze a jump from a crouching position using a variety of choices of system and tools: the Momentum Principle and the Energy Principle for both the real system and the point-particle / center-of-mass system.

I. Background

The work-energy relation applied to a real system says that the sum of the works done by each external force (which is that force integrated over the distance of its application) equals the change in the system's total energy, which it's often convenient to break up into the translational kinetic energy and the internal energy.

$$W_{net} = \Delta E_{system}$$

$$\sum_i \int \vec{F}_i \cdot d\vec{r}_i = \Delta K_{trans} + \Delta E_{\text{int}}$$

Meanwhile, if you just integrate the net force applied to the system over the *displacement of its center of mass*, you get the change in the system's translational kinetic energy.

$$\int \vec{F}_{net} \cdot d\vec{r}_{CM} = \Delta K_{trans} = \Delta\left(\tfrac{1}{2} M v_{CM}^2\right)$$

As for force-momentum relation applied to a real system, the sum of forces multiplied by the times over which they are applied, i.e., the impulses, gives the change in the net momentum of the system which is approximately (for speeds << c) the total mass times the change in its center of mass velocity.

$$\vec{I}_{net} = \Delta \vec{P}_{system}$$

$$\int \vec{F}_{net}(t) \cdot dt \approx \Delta\left(M \vec{v}_{CM}\right)$$

(I'm explicitly noting that the net force can be time dependent; as will happen in this lab, one individual force may remain constant while another varies.)

II. Experiment

A force plate will measure the upward force exerted by the floor on the jumper. A motion sensor will keep track of the location of the jumper.

A. Set Up

- Open the file "jump.cmbl".
- "Zero" the motion sensor so it considers the top of the force plate the origin. It will measure positions above that as positive.
- "Zero" the force plate *with the jumper standing on it.*
- Determine the weight and mass of the jumper using the force plate (thusly zeroed, the plate will report the jumper's weight when he/she's *not* standing on it.)

B. Data Collection

- With the jumper crouched on the force plate and *not* moving (and holding the cardboard box on his/her head to give the motion sensor a nice flat target), press the "Collect" button in LabPro. After the motion sensor starts clicking rapidly, the person should jump without bending the upper body (so that measured displacement of his/her head will be roughly the same as the displacement of his/her center of mass.)

- From the plots, read off the height of the jumper when *crouched* down before jumping and the corresponding time. It may be handy to use the "examine" function under the "analyze" menu.
- From the plots, read off the height of the jumper when just *leaving* the force plate and the corresponding time. To do this, identify the time when the force plot levels off because the jumper's leaving the plate, then read the corresponding height from the position plot.
- From the plots, read off the *peak* / maximum height of the jumper and the corresponding time.
- From the Force vs. time graph, you can determine the net impulse during the launch, i.e., $\vec{I} = \int \vec{F}_{net} dt$, graphically by finding the area under the graph from t_c *to* t_L.
    - To do this, highlight the force vs. time graph between these two times and then select "integral" under the "analyze" menu.

- One last value that you need from your data is the "work" that would be done to the center-of-mass system during the launch, $\int_{y_c}^{y_L} \vec{F}_{net} \cdot d\vec{r}_{CM}$. Graphically, that would be the area under an F_{net} vs. center-of-mass position plot, evaluated from y_L to y_c.
    - To do this, first go to the data table and highlight all the data from *before* time t_c, and then, under the "edit" menu, select "strike through." Do the same for all the data *after* time t_L. Now, one your force vs. time plot, click on the bottom axis label, "time" to get a menu of other options and select "position." Now, you can use the "integral" function on the "analyze" menu.

III. Analysis

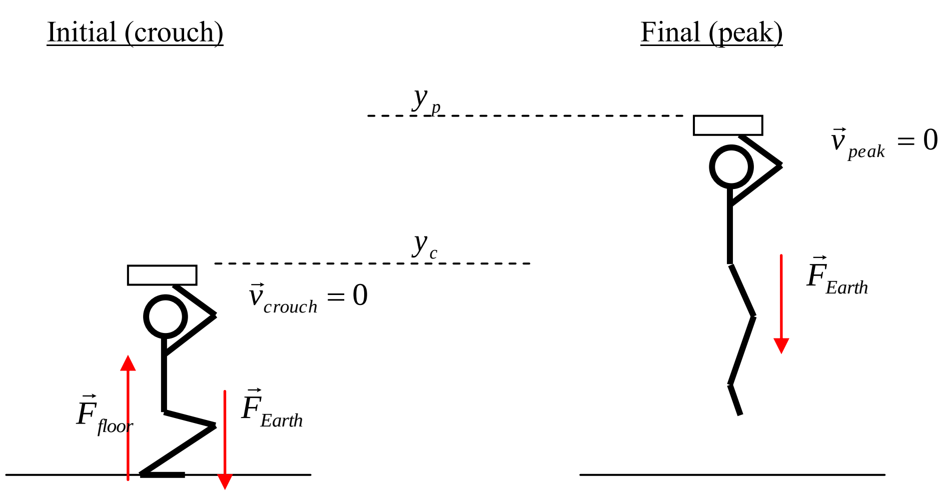
For each part, read very carefully what to use as the system, the initial state, and the final state.

A. Energy Principle for the ***Real System*** *– crouch to peak*

Following the steps below, use the energy principle for the real system of *only the jumper* going from *crouch* to the *peak* of the jump, to determine the approximate change of internal energy of the jumper (ΔE_{int}). Factors that you need to consider are:

1. Translational Kinetic Energy of the jumper
2. Forces exerted on the jumper by the Earth and the Floor
3. Net displacement of the point of application of each force (the gravitational force can be thought of as acting at the center of mass)
4. Work done by each force

- Consider the initial and final situations illustrated below.



- Write the energy principle symbolically (no numbers!) for this situation and choice of real system. Be sure to include the internal energy of the jumper. Get ΔE_{int} in terms of, *m, g,* y_p and y_c. Be careful about signs. (Are all quantities used labeled in the diagram above?)

  Pause and Consider: How much work was done on the real system by the floor? Why?

- Solve for a numerical value of the change of internal energy of the jumper (which we'll define to include kinetic energies of arm flailing, etc.) Show *all* of your work.

Pause and Consider: What sign for ΔE_{int} makes sense: are you gaining internal energy (+) or expending internal energy (-).

Questions: If the jumper didn't flail much, then most of that change in internal energy was on the microscopic scale; we could conceptually break that into the energy associated with flexing inter-atomic bonds, $E_{thermal}$, and that associated with making and breaking such bonds, $E_{chemical}$. Suppose that the change of internal energy can be attributed to just these two, $\Delta E_{\text{int}} = \Delta E_{\text{therm}} + \Delta E_{\text{chem}}$. What is the sign of the change in thermal energy? Explain. What can you say about the size of the change in chemical energy?

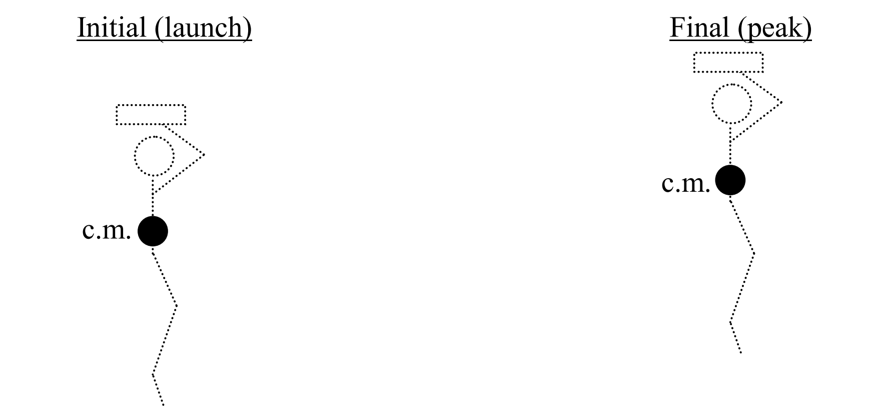
B. *Energy Principle for* ***Center-of-Mass*** *– Launch to Peak*

Use the energy principle for the *jumper's Center-of-Mass*, going from liftoff (when feet just leave the ground) to the peak of the jump, to determine speed of the jumper's center of mass at liftoff, v_L. Factors that you need to consider are:

1. Translational Kinetic Energy of the jumper
2. Net force exerted on the center-of-mass system
3. Net displacement of the center-of-mass system
4. Work done on the center-of-mass system by the net force

Question: Why don't you have to consider the internal energy of the jumper in this case?

- To help answer the next question, on a white board you may want to reproduce the sketch (below) of the initial and final states and then clearly label the important quantities in the diagram. (Remember, if you expect a property's value to change, then use *different* labels for it at *different* times.)



- Apply the energy principle symbolically (no numbers!) for this situation and choice of center-of-mass system. Get an expression for v_L in terms of *m, g,* y_p, and y_L. Be careful about signs.

- Solve for a numerical value the speed v_L of the jumper's center of mass at lift-off. Show *all* of your work.

*C. Energy Principle for the **Center-of-Mass** System – Crouch to Launch*

Following the steps below, you'll use the energy principle for the *center-of-mass / point particle system* describing the jumper, going from the crouched position to liftoff (when feet just leave the ground) in order to determine speed at liftoff, v_L, that *that* analysis predicts. Factors that you need to consider are:

1. Translational kinetic energy associated with the center-of-mass
2. Net force exerted on the system
3. Work done on the center-of-mass by the net force as it moves (*not* constant in this case!)

- To help answer the following questions, on a whiteboard, sketch this interval's initial (crouched) and final (lift off) situations and clearly label the important quantities in the diagram. (Remember to use *different* labels for *different* quantities.)
- Write the energy principle symbolically (no numbers!) for this situation and choice of point-particle system. Get an expression for v_L in terms of W_C and m. Be careful about signs.
- Solve for a numerical value the speed v_L of the jumper's center of mass at lift-off. Show *all* of your work.

D. Momentum Principle – Crouch to Launch

By following the steps below, you'll use the momentum principle for the system of *only the jumper* going from the crouch to liftoff, so you can see how this approach yields the speed of the jumper at liftoff, v_L .

- On a whiteboard, draw the initial and final situations. Clearly label the important quantities in the diagram; recall that, while the energy principle relates forces, distances, and speeds, the momentum principle relates forces, *times,* and *velocities*.
- Write the momentum – impulse relation symbolically (no numbers!) for this situation and give an expression for v_L in terms of I_{net} and m. Be careful about signs.
- Solve for a numerical value the speed v_L of the jumper at lift-off. Show *all* of your work.

E. One Final Analysis

Pause and Consider: You've determined the launch speed three different ways: Energy Principle from crouch to launch, Energy Principle from launch to peak, and Momentum Principle from crouch to launch. What's the 4^{th} way?

- On a whiteboard, sketch the appropriate initial and final situations and label the relevant properties.
- With the sketch's help, symbolically solve for the launch speed in terms of these properties.
- Then use that relation and the values you have measured for these properties to calculate the launch speed.

Question: Given perfect measurements, all four of these techniques would yield the exact same value for launch speed, but our measurements weren't perfect. Are the speeds at liftoff calculated in the four different ways fairly consistent (won't be perfect)?