Mini-lab: Jumping up

Analysis of a phenomenon in terms of the real system and the point particle system

Everyone fills out a copy of this worksheet.
Clip or staple all copies for your group together, making sure that everyone has all of the data and analyses.
Include appropriate units with your measurements and calculations.

Lab Section___________ Print your name____

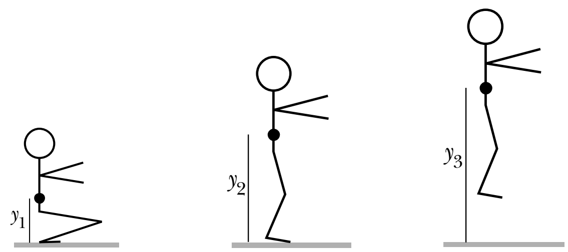
In this mini-lab you will fully analyze what happens in a jump upward from a crouching position. You will apply the energy principle to the real system of the jumper and also to the point particle system for the jumper. You will also apply the momentum principle in order to determine the short time of contact with the floor. These analyses provide an important review of the energy principle and the momentum principle.

Experimental observations

Form a group of three people. You'll need a meter stick.

- Each person crouches down, then jumps upward as high as possible, starting from rest. ***Jump HARD!!***
- While the jumper is crouched down, measure the height of the estimated location of the jumper's center of mass y_1 above the floor.
- Have the jumper stand up in a stretched position, approximating the position the jumper will have just as the feet lose contact with the floor in the jump. Measure the height y_2 of the estimated location of the jumper's center of mass at this take-off point.
- Now have the jumper crouch down again and jump upwards as hard as possible, starting from rest. Measure the height y_3 of the estimated location of the person's center of mass at the highest point of the jump.
- Estimate the mass m of the jumper.
- Record the data for each jumper. Note that 1 kg is 2.2 pounds.

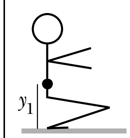
Name of jumper	y_1, m	y_2, m	y_3, m	m, kg



Analysis of experimental observations

Using the energy principle for the real system consisting of the jumper alone, determine how much chemical energy is expended.

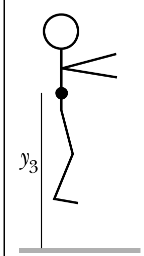
Use $\boldsymbol{m}$ for the mass of the jumper and $\boldsymbol{y_1}$, $\boldsymbol{y_2}$, and $\boldsymbol{y_3}$, for the three key heights of the center of mass.
Be careful of signs.
Do not plug in any numbers until later.



Initial translational kinetic energy (at y_1, just before starting to jump): $K_{trans,1}$ =

Final translational kinetic energy (at y_3, the highest point of the jump): $K_{trans,3}$ =

Force exerted on the jumper by the Earth: $\vec{F}_{Earth}$ = < __________, ___________, __________ >



Net displacement of the point of application of the gravitational force (which acts at the center of mass):

$\Delta\vec{r}$ = < ____________, _____________, ____________ >

Work done on the jumper by the force exerted by the Earth: W_{Earth} =

Work done on the jumper by the force $\vec{F}_{Floor}$ exerted by the floor on the bottom of the feet: W_{floor} =

Why is W_{floor} = 0? ____

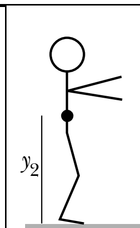
Write the energy principle for *this* situation and choice of real system. Be sure to include the term $\Delta E_{internal}$, the change of internal energy of the jumper. Be careful of signs.

Solve for the internal energy change in the jumper: $\Delta E_{internal}$ =

Why is $\Delta E_{internal}$ *negative*? ____

Using the energy principle for the point particle system for the jumper, going from lift-off (y_2) to the top of the jump (y_3), determine the speed of the jumper's center of mass at lift-off.

Use $\boldsymbol{m}$ for the mass of the jumper and $\boldsymbol{y_1}$, $\boldsymbol{y_2}$, and $\boldsymbol{y_3}$, for the three key heights of the center of mass.
Be careful of signs.
Do not plug in any numbers until later.



Initial translational kinetic energy (at y_2, lift-off, when feet just leave the floor): $K_{trans,2}$ (unknown)

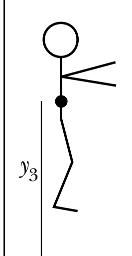
Final translational kinetic energy (at y_3, the highest point of the jump): $K_{trans,3}$ =

Net force exerted on the point particle system: $\vec{F}_{net}$ = < __________, ___________, __________ >

Net displacement of the point particle system: $\Delta\vec{r}$ = < __________, ___________, __________ >

Work done on the point particle system by the net force: W =

Write the energy principle for *this* situation and choice of point particle system. Be careful of signs.

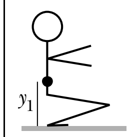


Solve for the translational kinetic energy at lift-off: $K_{trans,2}$ =

Solve for the speed of the jumper's center of mass at lift-off: v_2 =

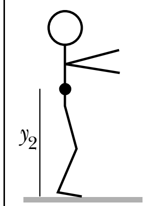
Using the energy principle for the point particle system for the jumper, going from the crouch (y_1) to lift-off (y_2), determine the magnitude F_{floor} of the force that the floor exerts on the bottom of the jumper's feet. Assume that this force is approximately constant while the feet are in contact with the floor.

Use ***m*** for the mass of the jumper and $\boldsymbol{y_1}$, $\boldsymbol{y_2}$, and $\boldsymbol{y_3}$, for the three key heights of the center of mass.
Be careful of signs.
Do not plug in any numbers until later.



Initial translational kinetic energy (at y_1, just before starting to jump): $K_{trans,1}$ =

Final translational kinetic energy (at y_2, lift-off, when feet just leave the floor; get this result from your preceding analysis): $K_{trans,2}$ =



Net force acting on the point particle system: $\vec{F}_{net}$ = < ___________, ____________, ___________ >

Net displacement of the point particle system: $\Delta\vec{r}$ = < ___________, ____________, ___________ >

Work done on the point particle system by the net force: W =

Write the energy principle for *this* situation and choice of point particle system. Be careful of signs.

Solve for the magnitude of the force exerted by the floor: F_{floor} =

This tells how strong the floor must be. If the floor cannot support a force this large, it will break. Note that F_{floor} is *larger* than the weight *mg* of the jumper.

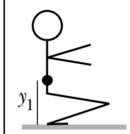
Why does the force of the floor, F_{floor}, appear in this analysis but not in the analysis of the real system which you did first? Write a very brief explanation:

Why is there no term $\Delta E_{internal}$ in this analysis?

Ask an instructor to check your work so far.

Using the momentum principle for the real system of the jumper (or for the point-particle system; the momentum principle is the same for both systems), going from the crouch (y_1) to lift-off (y_2), determine the amount of time Δt that the jumper's feet are in contact with the floor. Assume that the force of the floor F_{floor} is approximately constant while the feet are in contact with the floor.

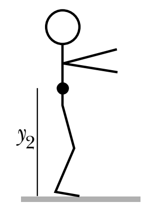
Use $\boldsymbol{m}$ for the mass of the jumper and $\boldsymbol{y_1}$, $\boldsymbol{y_2}$, and $\boldsymbol{y_3}$, for the three key heights of the center of mass.
Be careful of signs.
Do not plug in any numbers until later.



Initial momentum (at y_1, just before starting to jump):

$\vec{p}_i$ = < __________, ___________, __________ >

Final momentum (at y_2, lift-off, when feet just leave the floor; write in terms of the speed v_2):



$\vec{p}_f$ = < __________, ___________, __________ >

Net force exerted on the point particle system (write in terms of F_{floor}):

$\vec{F}_{net}$ = < __________________, __________________, _________________ >

Write the momentum principle for *this* situation and choice of system. Be careful of signs.

Solve for the amount of time that the jumper's feet are in contact with the floor:

Δt =

Note that the momentum principle always involves the *net* force, the vector sum of all the forces acting on the system. Also note that F_{floor} must be larger than mg in order to increase the upward momentum.

Now plug in numbers for each jumper. Note that the floor must support *more* than the jumper's weight.

Name of jumper	$\Delta E_{internal}$, J	Lift-off v_2, m/s	F_{floor}, N	Weight mg, N	Δt, s

Reflection: Look back over this mini-lab with your partners. What was the purpose of this mini-lab? What is different about the real system and the point particle system? When asked to do similar analyses on a quiz or test, without the step by step guidance provided here as an introduction, could you now do it?

What energy term is present in the energy principle for the real system but not for the point particle system?

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What work term is present in the energy principle for the point particle system but not for the real system?

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Review the instructions at the start of this worksheet.