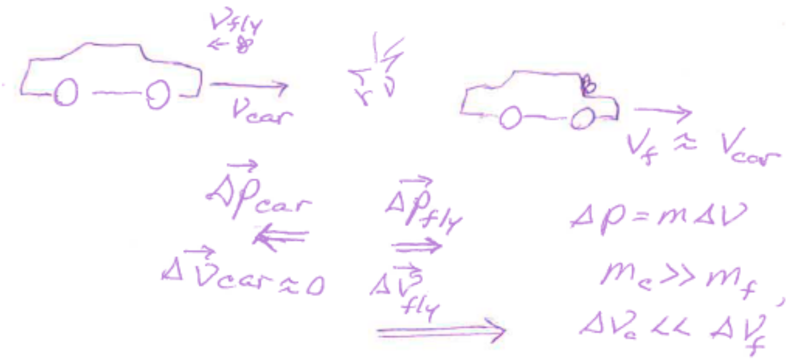
Problem Set #1, PHYS 141, Schwartz, Due the beginning of class, Monday, Sept. 18

Please read textbook sections 1.0 – 1.4. While you are reading, please address the exercises. In particular, please do and hand in the following:

1. Exercise 1 in section 1.0, Describing your Problem-Solving Experience *I received lots of interesting answers for this question last quarter. Folks expressed that they appreciated the expedience of just using a formula. Additionally, most people expressed greater appreciation and satisfaction when they used concepts.*

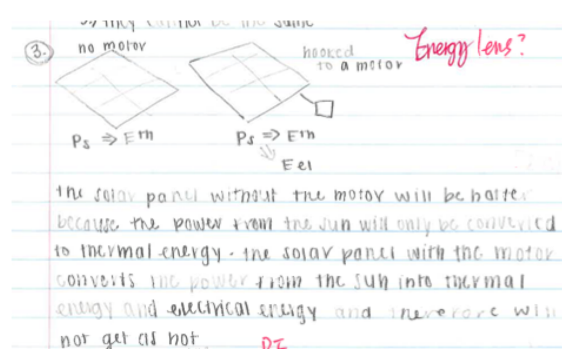
2. Exercise 1 in section 1.1, fly and window collision

*This question and the "pushing off the boat" question (1.3 Ex.1) are essentially identical questions: pushing off something is like a collision in reverse, all the same laws hold. There is a force between the two objects, affecting each in opposite directions with same magnitude (because it's the same force). Because there are no outside forces, there is no change in momentum, so these two objects just exchange momentum. Each getting the same amount, but in opposite directions. These two observations are totally consistent because dp = F*dt. This doesn't mean that the acceleration or change in velocity of the two bodies is the same because they can have different masses. The extreme example is the fly on the windshield: they both have the same impulse (change in momentum), but because $m_{fly} << m_{car}$ the <u>effect</u> on each is very different. The car's velocity changes imperceptibly, and the fly's velocity changes a lot. For the pushing off the boat, imagine the difference if you push off the side of an ocean liner versus the side of an inflatable kayak.*

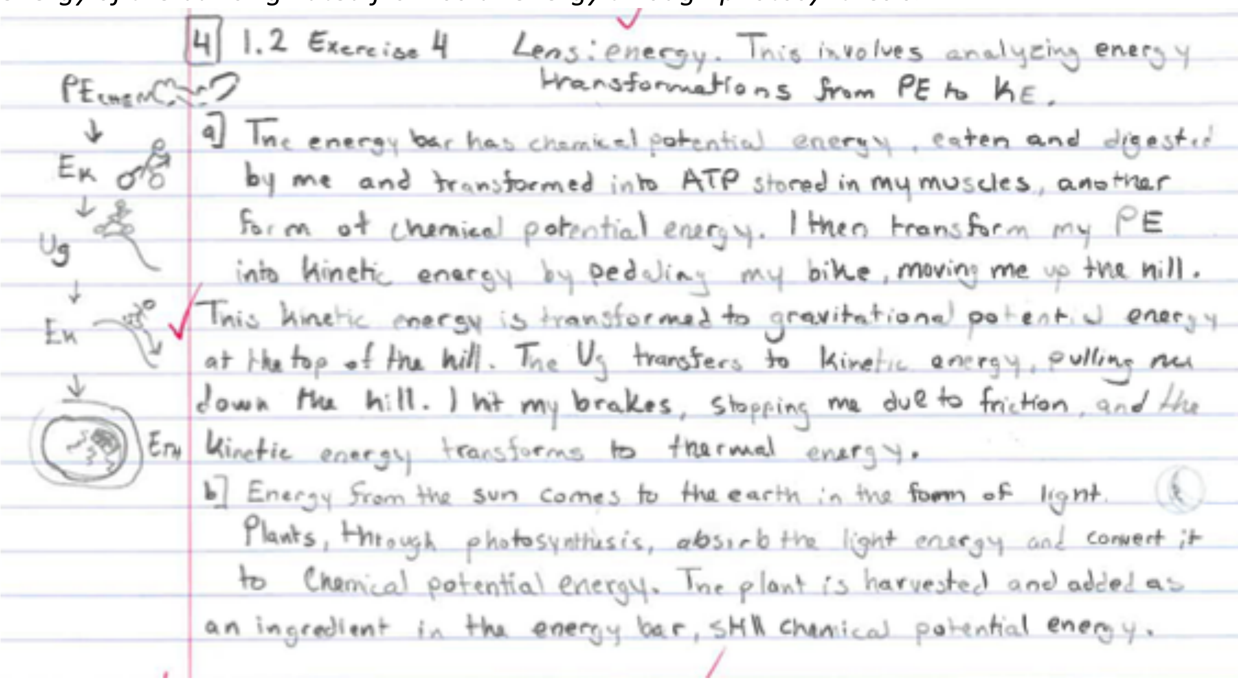


3. Exercise 3 in section 1.2, Solar Panels

The same amount of solar energy is absorbed. In one case, all this energy is converted to thermal energy. In the other case, it's converted to thermal energy and some electrical energy (to mechanical energy). If the energy can't go anywhere else, the solar panel connected to the motor receives less thermal energy and should therefore be cooler.



4. Exercise 4 in section 1.2, Energy Bar Bicycling *The chemical potential energy (sugar in the bar) => kinetic (and thermal) energy in my body to the kinetic energy of the bicycle to the increase in gravitational potential energy climbing the hill, back to kinetic energy at the bottom of the hill to thermal energy in my breaks to the radiation of infrared light out into space. The chemical potential energy of the bar originated from solar energy through photosynthesis.*


4 1.2 Exercise 4 Lens: energy. This involves analyzing energy transformations from PE to KE.

a] The energy bar has chemical potential energy, eaten and digested by me and transformed into ATP stored in my muscles, another form of chemical potential energy. I then transform my PE into kinetic energy by pedaling my bike, moving me up the hill. This kinetic energy is transformed to gravitational potential energy at the top of the hill. The U_g transfers to kinetic energy, pulling me down the hill. I hit my brakes, stopping me due to friction, and the kinetic energy transforms to thermal energy.

b] Energy from the sun comes to the earth in the form of light. Plants, through photosynthesis, absorb the light energy and convert it to chemical potential energy. The plant is harvested and added as an ingredient in the energy bar, still chemical potential energy.

5. Imagine yourself jumping ***horizontally*** (northward) off the side of a small boat by pushing with your legs.

a) Describe as completely as possible what the boat does during this process.

With a good drawing, we can use a force lens, or a momentum lens to indicate that as I push and move forward, the boat accelerates in the opposite direction.

b) Let's say you have a mass of 70 kg, the boat has a mass of 140 kg and you have a velocity of 6 m/s, horizontally after you push off (lasting 0.3 s). What's the speed of the boat?

Knowing that inside this system momentum is conserved because there are no outside forces, we know that the initial momentum is zero, so the final momenta must add to zero. The boat has twice the mass, so it must have half my speed, or 3 m/s

c) What was the average force from your legs on the boat?

I use a dynamics lens because the force of my legs causes the acceleration of my body (and the boat). I use a kinematics lens to calculate that I have an acceleration of 20 m/s^2. The force between the boat and myself must be 1400 N.

d) What was the average acceleration of the boat? ... follow the same three as above.

Knowng the force on the boat, we can find an acceleration of 10 m/s^2.

e) About how much work did I do in this process?... follow the same three as above.

Work is F*dx. However, it is also the change in energy. This is an energy lens. The work I do comes from chemical potential energy in my body, and turns into the kinetic energy of my body and the boat. We can find each of these kinetic energies because we know the masses and speeds of each. I get must under 1900 J. Am I correct?

6. Exercise 2 in section 1.4, Rocket taking off

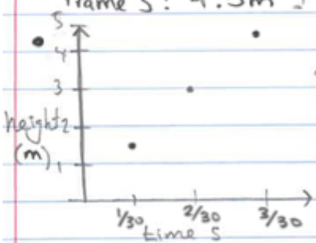
We use a kinematics (not kinetics. Kinetics means energy) lens because the video frames give us perfect measurement of position as an explicit function of time. Knowing that the frames are taken every 1/30 s. If the white launch tube is 60 cm high (and the boy is about 1.5 m tall), then the distance between the rocket positions in the first and second frame is about 2.25 m. We can use the definition of velocity to find a speed of about 67 m/s or about 155 mph!

Great!

$\boxed{6}$ 1.4 Exercise 2   Lens: kinematics: we are determining values based on data of time and position.

Frame 1: 1.5 m
Frame 2: 3 m
Frame 3: 4.5m

Data based to scale that the kid in the frames is approx 1 m tall.



$\text{speed} = \frac{1.5\text{m}}{1/30\text{ s}} = \boxed{45\ \text{m/s}}$

$\frac{45\text{m}}{\text{s}} \times \frac{60\text{s}}{1\text{min}} \times \frac{60\text{ min}}{1\text{hr}} \times \frac{\text{km}}{1000\text{m}} \times \frac{1\text{ mi}}{1.61\text{km}} = \boxed{100\ \text{mi/hr}}$

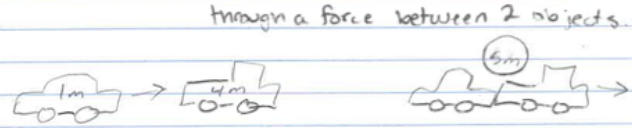
This is fast! I am surprised but don't think it unreasonable.

7. Exercise 3 in section 1.4, Car Collision

1. *I will choose to use a momentum lens because during the collision, the outside forces are negligible, so the system momentum should not change. My first step is to make sure* $\sum \Delta p_o = \sum \Delta p_f$. *I get* v_f *= 4m/s.*
2. *and 3. This is a straight mathematical calculation, definition of momentum. The change in momentum is 16,000 kg m/s. The change in momentum for the truck is forward, and that of the car is in the opposite direction.*

4. Momentum is conserved because these equal momentum changes are in opposite directions, so the sum of these changes is zero.

$\boxed{7}$ 1.4 Exercise 3   Lens: momentum because there are no outside forces and the transfer of momentum through a force between 2 objects.



$\boxed{1.}$ $V_o = 20$ m/s $P = mv$ momentum is conserved, so with increased mass, velocity must decrease.

$\boxed{V_f = \frac{1}{5}V_o} = \frac{1}{5}20\text{ m/s} = \boxed{4\ \text{m/s}}$

2. $m_C = 1000\,kg$ $\quad p_C = m_C \Delta v$ $\quad p_T = m_T \Delta v$

$m_T = 4000\,kg$ $\quad = (1000\,kg)(-16\,m/s)$ $\quad = (4000\,kg)(4\,m/s)$

$\boxed{p_C = 16000\,\frac{kg\,m}{s}}$ $\quad \boxed{p_T = 16000\,\frac{kg\,m}{s}}$

↳ negative direction ↳ positive direction

3. Δv of car $= 4\,m/s - 20\,m/s$ $\quad \Delta v$ of truck $= 4\,m/s - 0\,m/s$

$= -16\,m/s$ $\quad = 4\,m/s$

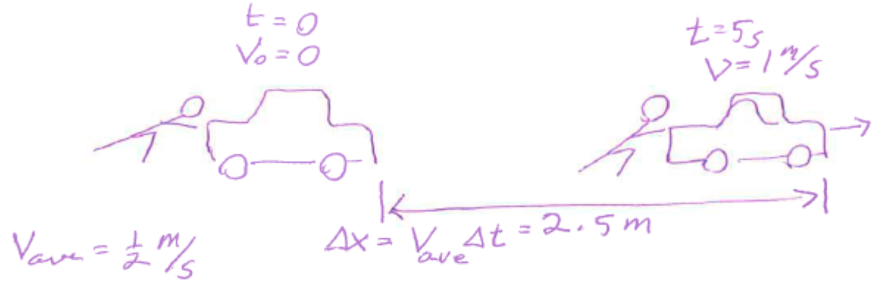
4. Yes momentum is conserved because they have to be equal

8. Exercise 1 in chapter 1.5, rocket acceleration.
We use a kinematics lens because we know the position of the rocket as an explicit function of time by looking at the video frames. The rocket has enormous acceleration at takeoff! The speed changes from zero to about 67 m/s in 1/30 of a second or less, because it could have made the change in much less than one video slide. Thus, the acceleration is at least 2000 m/s^2, or 200 gravities. This acceleration would instantly kill a person. The rocket's velocity doesn't change much after it takes off, as determined by the near equal distances travelled between the second - third frame transition, and the first- second frame transition. However, if we look closer, it seems the rocket moved about 225 cm between the first and second frame, and about 195 cm between the second and third frame, corresponding to a reduction in speed of about 9 m/s. This change would have taken place in 1/30 of a second, corresponding to an acceleration of 270 m/s^2 slowing the rocket – way less than the 2000 m/s^2 at take-off, but still more than gravity. However, there is significant air friction acting on the high-speed rocket. Because the rocket has very little mass (using a dynamics lens because the frictional and gravitational forces cause the rocket to accelerate), the acceleration, a = F/m can be pretty high.

9. Taken from Exercise 3 in chapter 1.5. *Please be mindful <u>to identify</u> a lens for each step*:
You push a 1000 kg car from rest on smooth level ground. It takes you 5 s to get the car to a speed of 1 m/s.
    a) *What is the car's acceleration? This is a kinematics lens, because we are looking only at the car's motion as it evolves in time. We use the definition of acceleration to find the car's acceleration to be 0.2 m/s^2.*
    b) *What is the force you are exerting on the car? This is a dynamics lens because the force is causing the car to accelerate. Using F = ma, we can find a total force of 200 N.*
    c) *How does this force compare with the force of gravity on your body? Again, we can use a dynamics lens because gravity acting on my body would cause it to acceleration at 10 m/s^2. Thus, the force from gravity on my 70-kg body is about 700 N. So, I'm not pushing as hard on the car as gravity is pulling on me.*
    d) *Please imagine doing this in your mind. Does this sound reasonable? I personally imagine that I'd have to give the car a nudge of greater force to break the frictional force that keeps it from starting. However, if the 1000 kg car were instead a 1000 boat floating tranquilly at a dock, then this would make sense.*

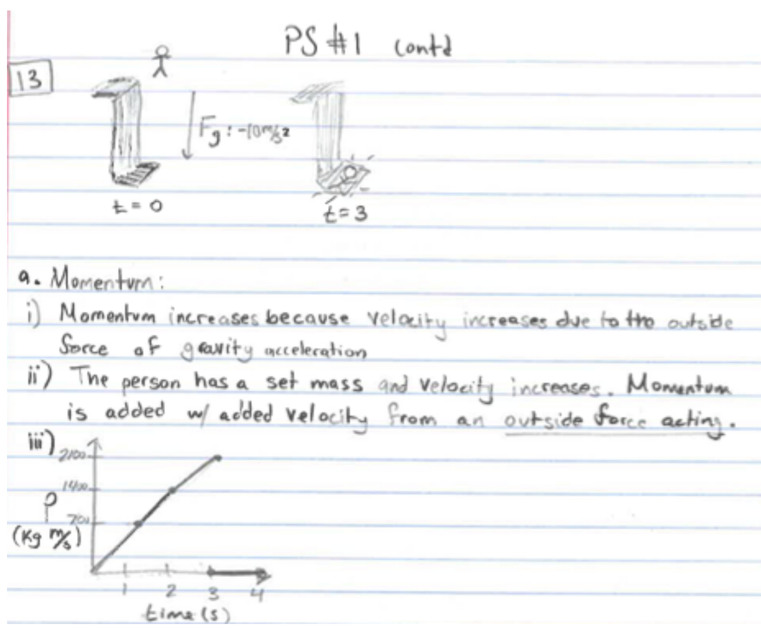
e) *Estimate the power you put out accelerating the car. I will use an energy lens because my work is transformed into kinetic energy of the car = ½ mv^2, or 500 J. Power is the rate of change of this energy. Thus, the average power over the 5 seconds is 100 W.*

This is the first problem that requires the use of force units, the Newton, N. I haven't defined this unit, but we have defined and spoken about force already. Can you describe a Newton in terms of other more basic units to do this problem?



10. Please read through exercise 8 in 1.6. What does this tell you about conservation of energy versus conservation of *kinetic* energy in a collision?
*Total energy is always conserved. In a collision, no outside work is done, so total energy must be conserved. However, we see that kinetic energy (mechanical energy) is lost in the inelastic collision. Some of the mechanical energy is changed to thermal energy. The take-away from this is that we **can't** use conservation of (kinetic) energy to solve for speeds in an inelastic collision. We should use a momentum lens because if there is no outside force, total momentum of a system won't change.*

11. I inadvertently walk off a cliff. The process comes to a grim result 3 seconds later when I meet the ground. Please look at this process closely through all 4 lenses.
NOTE: These questions may not be in the best order for answering them. My advice is to look through all of them quickly and start thinking about what's happening… did you make a drawing? That's usually the most important step in problem analysis.



a) Momentum: *The key here is that momentum is conserved only if the outside force is zero. In this case, the force of gravity (and the normal force when I hit the ground) acts between me and the earth, by which we exchange momentum. There is no external force on the me-earth system, so **the system's** total momentum (me and the earth) is conserved.*
   i) How does my momentum change during the three seconds and thereafter? *My downward momentum increases and then at the end suddenly changes back to zero from a short, intense normal force.*

ii) Why should this be the case? *Using a momentum lens, the earth's momentum is equal and opposite to mine, but we don't notice this motion because the mass of the earth is so large that changes speed imperceptibly.*

iii) Can you make a rough graph of my momentum as a function of time from 0 seconds to 4 seconds?

iv) Is momentum conserved during this process? Did I break the law of conservation of momentum? *The total momentum of the me-earth system remains constant.*

v) If it's true that momentum inside of a closed system must be conserved, please describe the full system we're talking about here. *Again, the system is the me-earth system.*

b) Energy:

i) Please identify energy transitions or state why there are none. *The gravitational potential energy of me and the earth transitions to kinetic energy, and then to thermal energy.*

ii) What is the energy at the very beginning? What is the form of energy at the very end? *See above.*

iii) Was energy conserved? Please describe. *Energy is conserved but changes form.*

c) Forces:

i) Is there a force or forces acting on me? Please identify. *There is an attractive gravitational force between me and the earth, and there is a repulsive normal force between us at the end.*

ii) I've defined a force as an interaction between two bodies whereby momentum is transferred. Can you identify two bodies? What do we mean by momentum is transferred? What is happening? *Attractive gravitational force imparts equal and opposite momenta onto me and the earth as we fall together. The repulsive normal force exchanges these momenta back so that each again has momentum of zero.*

d) Kinematics:

i) Can you describe my motion? What might my speed look like as a function of time. Can you make a speed vs time graph? *With constant acceleration, my velocity – time graph should be a straight line with a negate slope of ~10* m/s^2.

ii) Can you describe my height as a function of time? Can you make a height vs time graph? *The slope of this graph is the velocity, which is becoming more and more negative, so the graph curves downward in a parabolic shape.*

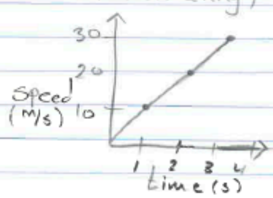
c. Forces

i) The downward force of gravity is acting on Pete. This force is = mass x $10 m/s^2$.

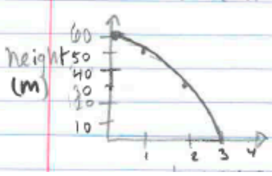
ii) The two bodies transferring momentum are the person and the earth. Whatever momentum is lost by one body in an interaction is gained by the other. The one body gains Velocity due to a force or interaction exchanging momentum.

d. Kinematics

i) Pete's motion: velocity is increasing as a function of time (accelerating) at a rate of $10 m/s^2$, yet constantly



ii) Height decreases faster and faster as time goes on since it is accelerating at $10 m/s^2$.



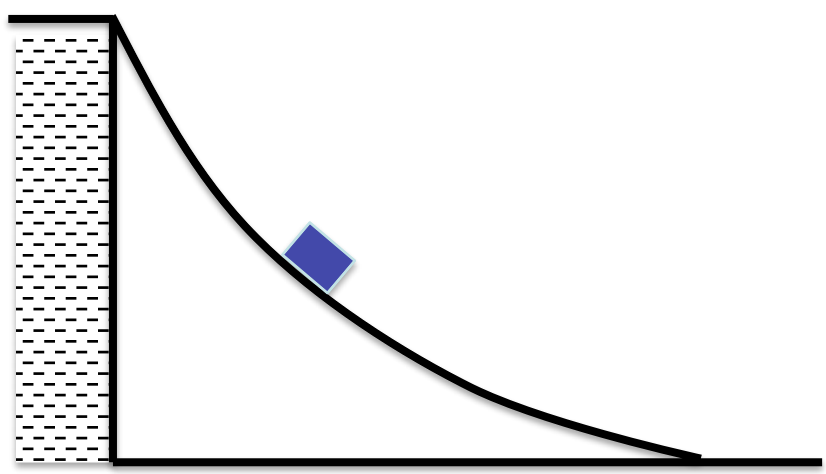
→ The slope becomes more and more negative, indicating more height drop as time increases

12. Imagine a 5 kg box sliding down a frictionless curved track at the edge of a 60 m high cliff as shown at right. We would like to know how fast it's going at the bottom. Neglect air friction.

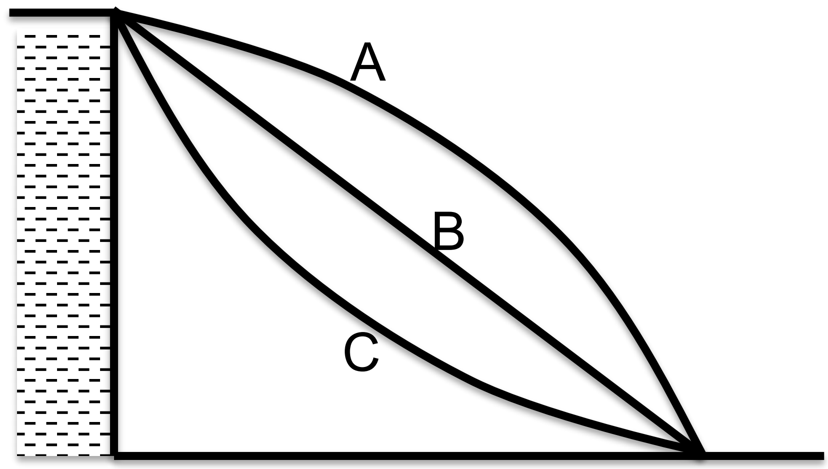
a) Describe using each of the four lenses, what is happening in this process.

b) Which lens is the most helpful to find the final speed of the block at the end?

c) Please find out the speed at the bottom of the track.



Now imagine that there are two other tracks that the box could use as shown at right, bottom.



d) Which track should we use for the fastest final speed, or would all three tracks yield the same final speed? Which lens do you look at this problem through? Please explain your answer.
e) How about if we wanted to know which was going the fastest *half way* down the total length of its path?
f) If three identical frictionless boxes were released at the top of each track, which would get to the bottom first, or would it be the same for all of them? Please explain your answer in terms of which lens you used.

The most useful lens is the energy lens because potential energy is being converted to kinetic energy as the box descends. Thus A, B, and C tracks all result in the same final speed because the same amount of potential energy is lost. Half way through, the box on C would have lost the most potential energy, so it would have the greatest amount of kinetic energy and thus the greatest speed. In fact, the box on C would have the greatest speed throughout the trip, so it would finish first, then the box on B, then A would finish last.
The other interesting lens (in my opinion) is the momentum lens. The momentum of the box changes significantly… so there must be an outside force with who? The EARTH! So we recognize that the earth must have acquired the opposite change of momentum as the cart gained. We see this in the class demo when the track is a cart on wheels rather than connected to the earth… the cart recoils in the opposite direction as the cart.

PS # 1 cont'd

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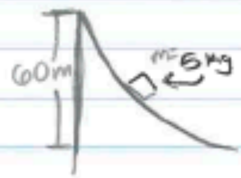

a.) Momentum: The force of gravity changes the velocity and therefore momentum of the box, so the box has momentum moving down the slope.
Energy: The box has gravitational Potential E at the top, which is converted to Kinetic E, moving it down the slope.
Forces: The force of gravity is causing acceleration and moving the box
Kinematics: The object's speed will become faster as a fn of time.

b) Energy is the most useful lens: potential energy transforms to kinetic and energy is conserved. ✓ Nice!

c) $V_g = mgh \quad E_k = \frac{1}{2}mv^2$

$$mgh = \frac{1}{2}mv^2$$

$$\cancel{(5kg)}(10\,m/s^2)(60\,m) = \frac{1}{2}\cancel{(5kg)}(v)^2$$

$$1200\,\frac{m^2}{s^2} = v^2$$

$$v = \sqrt{1200\,\frac{m^2}{s^2}} = \boxed{34.64\,m/s}$$ ✓

✓

d) Each track would yield same final speed, since masses are the same, height is same, and force of gravity is the same. I looked at this again through the energy lens ✓ as energy is conserved and transferred from gravitational potential to kinetic.