Ballistic Pendulum

Equipment: Nerf gun with bullet, empty bottle, string, ring stand, string and tape, meter stick, digital scale, phone to take video.

Procedure:

1. Measure and record the mass of the bullet and the bottle.
2. Load the Nerf gun with bullets. Aim the nerf gun right at the mouth of the bottle, but not touching it. Pull the trigger.
3. Use the video to measure the position of the bottle before it started moving and at its maximum height after the collision.

Data

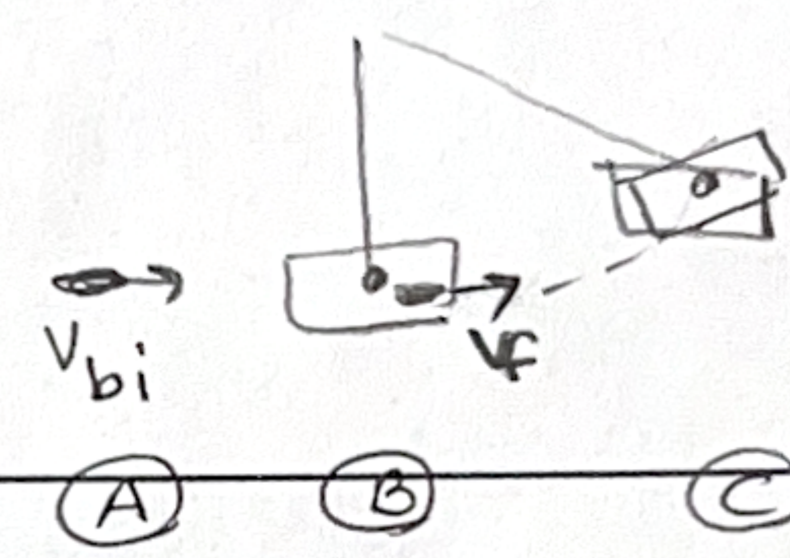
Mass of bottle: 20.9g

Mass of bullet: 1.2g

Initial position of bottle: 16.5cm

Position of bottle at maximum height: 20cm

Picture:



Tip: This situation involves two processes, one that happens right after the other. The first process is the collision between the bullet and the bottle. Immediately after this is the process of the bullet and bottle swinging up as a pendulum to a maximum height. Assume that the collision between the bullet and the bottle is completed before the bullet and bottle begin to swing upward.

1. Consider the process of the **collision between the bullet and the bottle.**

Initial moment: (A) Before bullet contacts bottle

Final moment: (B) Collision is complete, bottle + bullet are moving together horizontally $\xrightarrow{V_f}$

List all objects involved in interactions with the bullet and the bottle during this process:

bottle, bullet, earth, string

a. What objects would you put in the system and environment if you were analyzing this process using the momentum principle? *Try to define the system so the net external impulse in each direction is 0.*

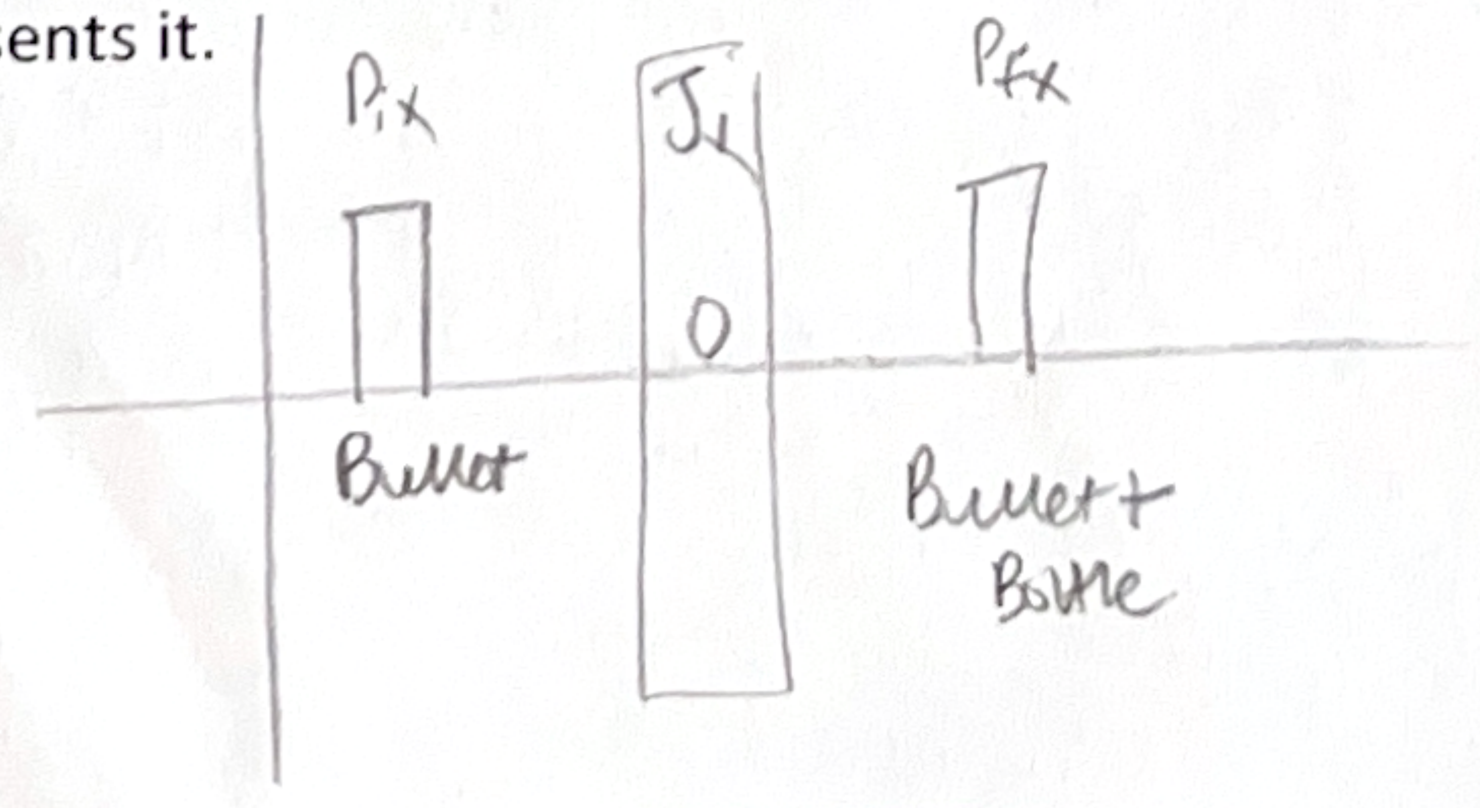
System: bottle, bullet Environment: string, earth

What external forces are there on this system? tension, F_G

Which, if any, external forces exert an impulse on the system? the net external force is 0

If any external impulses occur, is there a net Jx? no. Is there a net Jy? no

b. Draw a momentum bar chart for the x-direction for your system and write an equation that represents it.



$$P_{ix} + J_x = P_{fx}$$

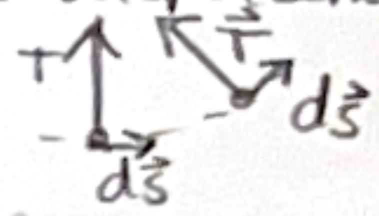
$$\boxed{m_b V_{bi} + 0 = (m_b + m_B) V_f}$$

Two unknowns

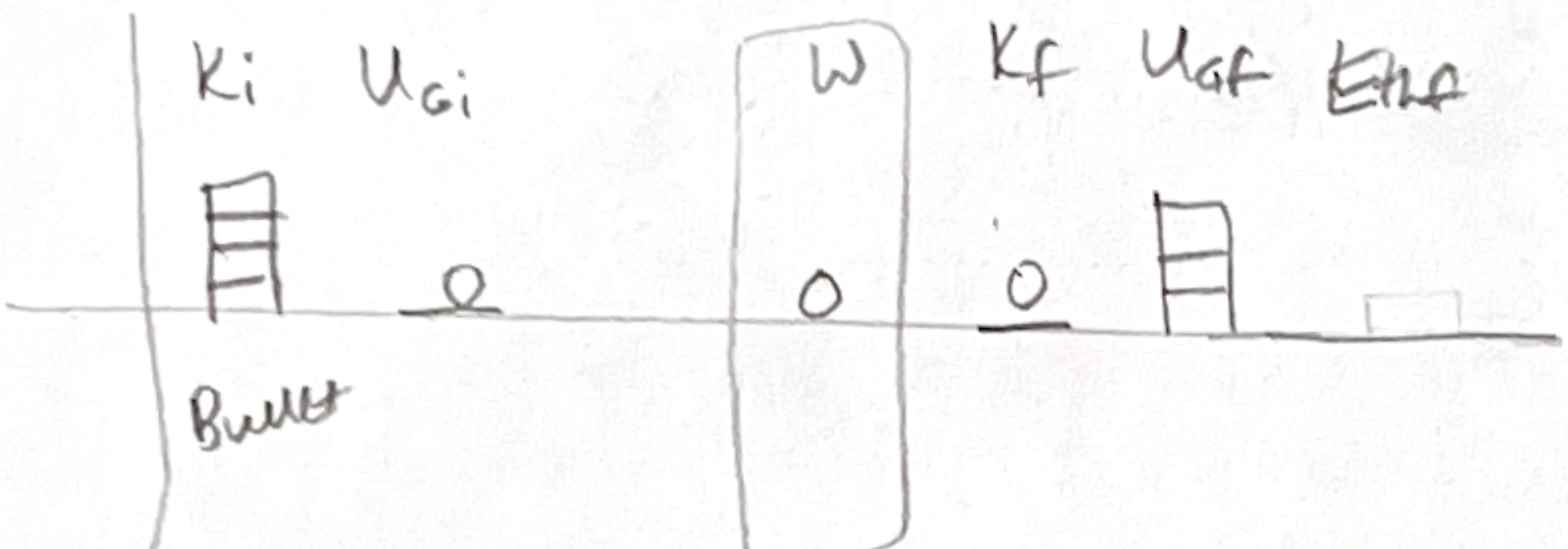
2. Consider the process of the **bullet and bottle's motion after the collision.**
Initial moment: B After collision, B and b moving together horizontally
Final moment: C B+b are at max height, V=0
List all objects involved in interactions with the bullet and the bottle during this process:
bullet, bottle, earth, string

a. What objects would you put in the system and environment if you were analyzing this process using the energy principle? *Try to define the system so the work done by external forces is zero.*

System: bullet, bottle, earth Environment: string
What external forces are there on the system? tension
Which, if any, external forces do work on the system? none. Tension is an external force, but it does no work because it is ⊥ to the displacement
If any external forces do work, identify the sign for each work done: ______



b. Draw an energy bar chart for this process and write an equation that represent is.



$E_i + W = E_f$

$K_{ib} = U_{gf} + E_{thf}$

$$\boxed{\frac{1}{2}(m_b + \cancel{m_B})v_f^2 = (\cancel{m_b + m_B})gh}$$

$\frac{1}{2}v_f^2 = gh$

3. Determine the speed of the combined bottle and bullet just after the collision — one unknown!

$\frac{1}{2}v_f^2 = gh$

$v_f = \sqrt{2gh}$

$= \sqrt{2(9.8)(0.035\,m)}$

$= \boxed{.83\ m/s}$

I am using energy to find velocity at B instead of momentum. This is because I do not have enough information to find it using momentum.

4. Determine the speed of the bullet just before it entered the bottle

$m_b v_{bi} = (m_b + m_B) v_f$

$(1.2g) v_{bi} = (1.2g + 20.9g)(0.83\,m/s)$

$v_{bi} = \boxed{15.3\ m/s}$

5. Calculate the amount of energy that is converted to thermal energy during the process of the collision between the bullet and the bottle.

$E_i + W_{ext} = E_f$

$0.140J + 0 = 0.0076J + E_{th}$

$\boxed{0.13J = E_{th}}$

Kinetic at A $= \frac{1}{2}(0.0012\,kg)(15.3\,m/s)^2 = .140\,J$

Kinetic at B $= \frac{1}{2}(0.0012\,kg + 0.0209\,kg)(0.83)^2 = .0076\,J$

Static and Kinetic Friction

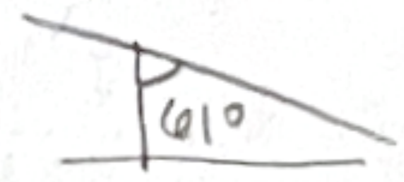
Equipment: Wood block, string loop, spring scale, table, protractor

(My data is for the wood block on a wood board instead of a classroom table.)

Procedure and Data:

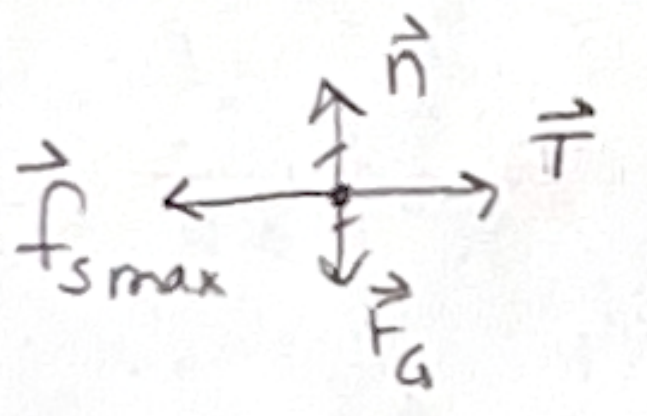
1. Measure the mass of the block: 357.8g = 0.3578kg
2. Attach the spring scale to the hook on the block using the loop of string.
   a. Pull horizontally with the spring scale and record the greatest pulling force at which the block remains at rest. 1.7N
   b. Pull horizontally with the spring scale to make the block move with a constant speed. Record the constant pulling force needed. 1.3N
3. Put the block on the table and tilt the table until you find the last angle at which the block remains at rest. Record this angle: 61° from vertical

   90−61° = 29° from horizontal



Analysis:

1. Process: Block is on the horizontal table while being pulled with the greatest force at which it remains at rest. Draw a FBD of the block and calculate the coefficient of static friction between the table and the block.



a=0

$\Sigma F_x = ma_x$

$T - f_{s\,max} = m(0)$

$T = f_{s\,max}$

$T = \mu_s n$

$T = \mu_s mg$

Find normal force:

$\Sigma F_y = ma_y$

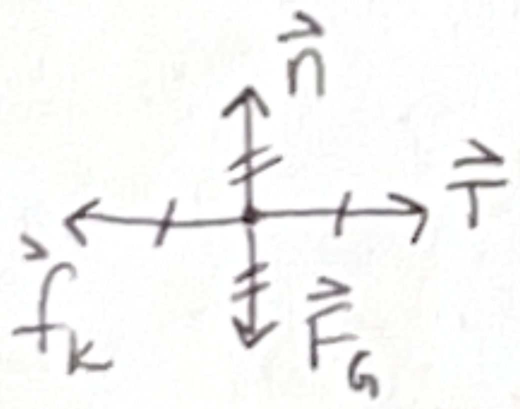
$n - mg = m(0)$

$n = mg$

$\mu_s = \frac{T}{mg}$

$\mu_s = \frac{1.7N}{(0.3578kg)(9.8N/kg)} = \boxed{0.48}$

2. Process: Block is being pulled with the force needed to make it move at a constant speed on the horizontal table. Draw a FBD of the block and calculate the coefficient of kinetic friction between the table and the block.



a=0 because $\vec{v}$ is constant

$\Sigma F_x = ma_x$

$T - f_k = m(0)$

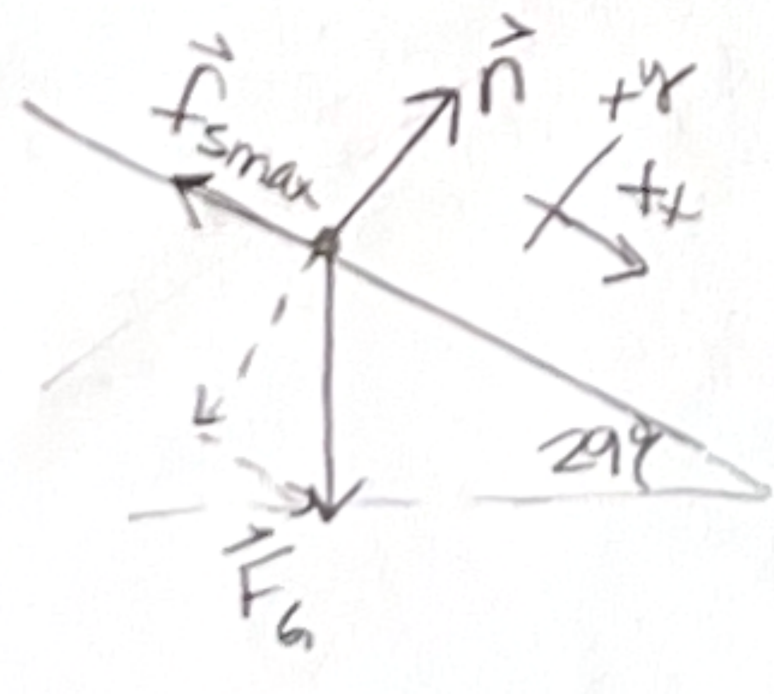
$T = f_k$

$T = \mu_k n$

$T = \mu_k (mg)$

$\mu_k = \frac{T}{mg} = \frac{(1.3N)}{(0.3578kg)(9.8N/kg)} = \boxed{.37}$

3. Process: Block is on the table, which is tilted at the last angle at which the block will remain at rest. Draw a FBD of the block and calculate the coefficient of static friction between the table and the block.



Forces	F_x	F_y
$\vec{n}$	0	n
$\vec{f}_{s\,max}$	$-\mu_s n$	0
$\vec{F}_G$	$mg\sin\theta$	$mg\cos\theta$
ΣF	0	0

$\Sigma F_x = ma_x$

$-\mu_s n + mg\sin\theta = 0$

$mg\sin\theta = \mu_s n$

$\cancel{mg}\sin\theta = \mu_s(\cancel{mg}\cos\theta)$

$\tan\theta = \mu_s$

$\tan(29°) = \mu_s$

$\boxed{.55} = \mu_s$

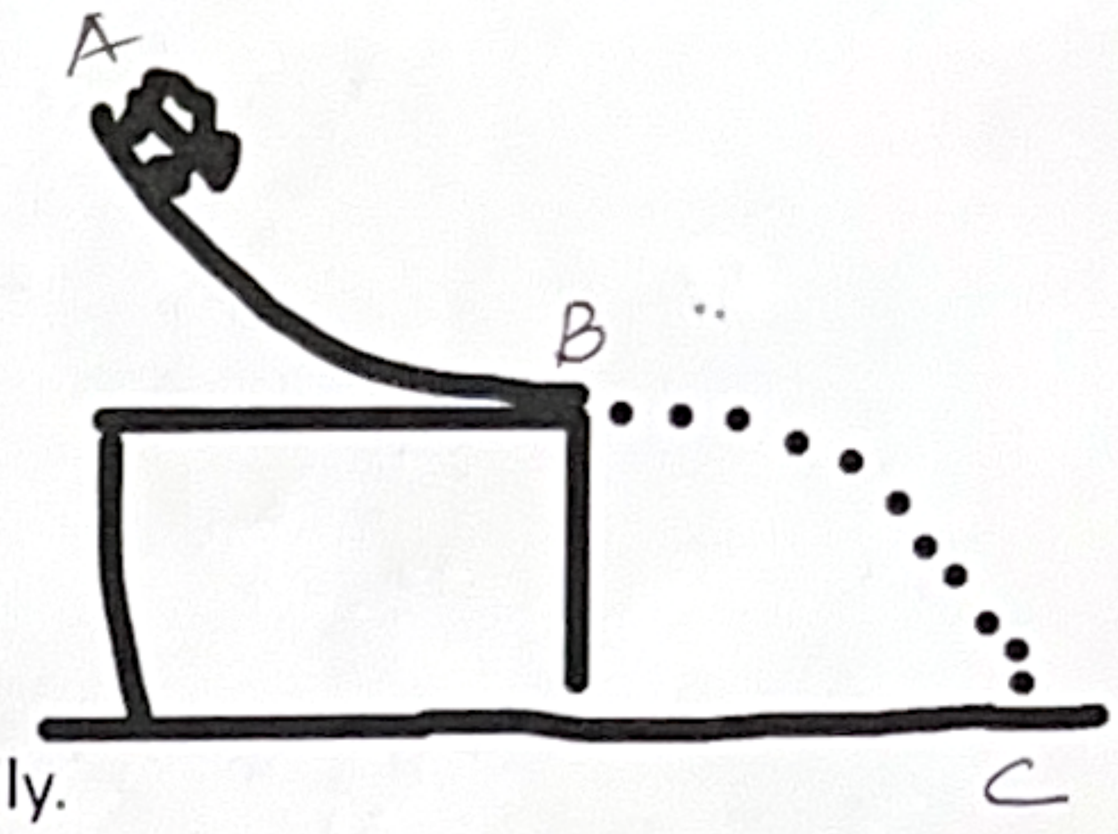
$\Sigma F_y = ma_y$

$n - mg\cos\theta = 0$

$n = mg\cos\theta$

Ideally, the values obtained in #2 and #3 would be the same

Car Over a Cliff



Equipment: Hot Wheels Track, car, table, meter stick, digital scale

Procedure and Data:

1. Set up the track so the car will leave the table moving horizontally.
2. Measure and record the mass of the car: 64 g*
3. Measure the height above the table that the car will be released from: 35.0 cm *
4. Release the car and mark the point on the floor where it lands. Measure the horizontal distance from the landing point to directly below the end of the track (the point where the car left the table.) 95.2 cm *
5. Measure the vertical distance from the end of the track (the point where the car left the table) to the floor: 75.4 cm *

* These values are not actual measurements.

Analysis: This situation involves two processes, one that happens right after the other. The first process is the motion of the car down the ramp. Immediately after this is the process of the car moving as a projectile in the air. Assume that there IS friction between the car and the ramp, but that air resistance is negligible throughout both processes.

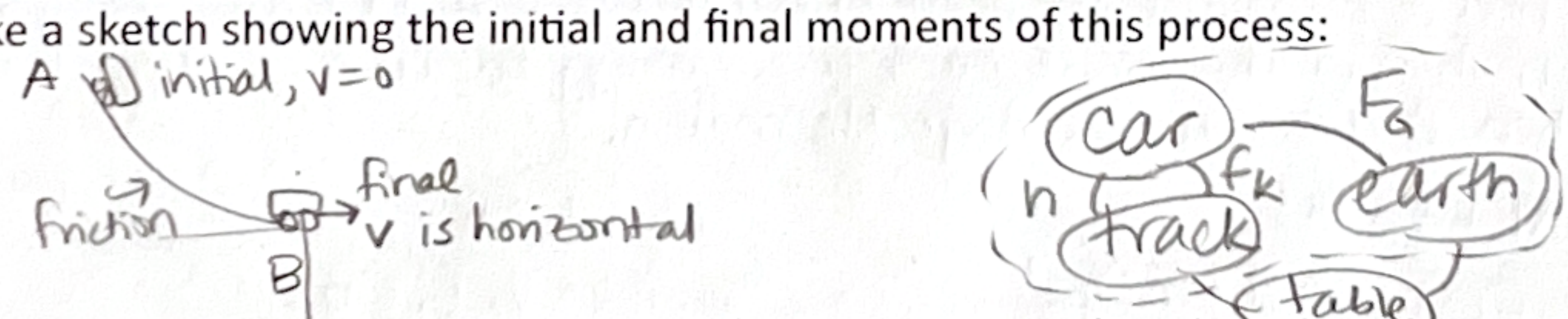
The general approaches we have learned so far are: *1-D kinematics, 1-D forces, Momentum Principle, Energy Principle, Projectile Motion (2-D kinematics and forces) and Circular motion (2-D kinematics and forces).*

1. What general approach(es) do you think would be most useful for analyzing the process of the car moving down the ramp? Energy Principle

2. What general approach(es) do you think would be most useful for analyzing the process of the car moving in the air? Energy Principle, Projectile motion

3. Consider the process of the **car moving down the ramp**

a. Make a sketch showing the initial and final moments of this process:



b. If you were going to analyze this using the Energy Principle, what objects would you put in the system? *Try to define the system so the work done by external forces is zero.*

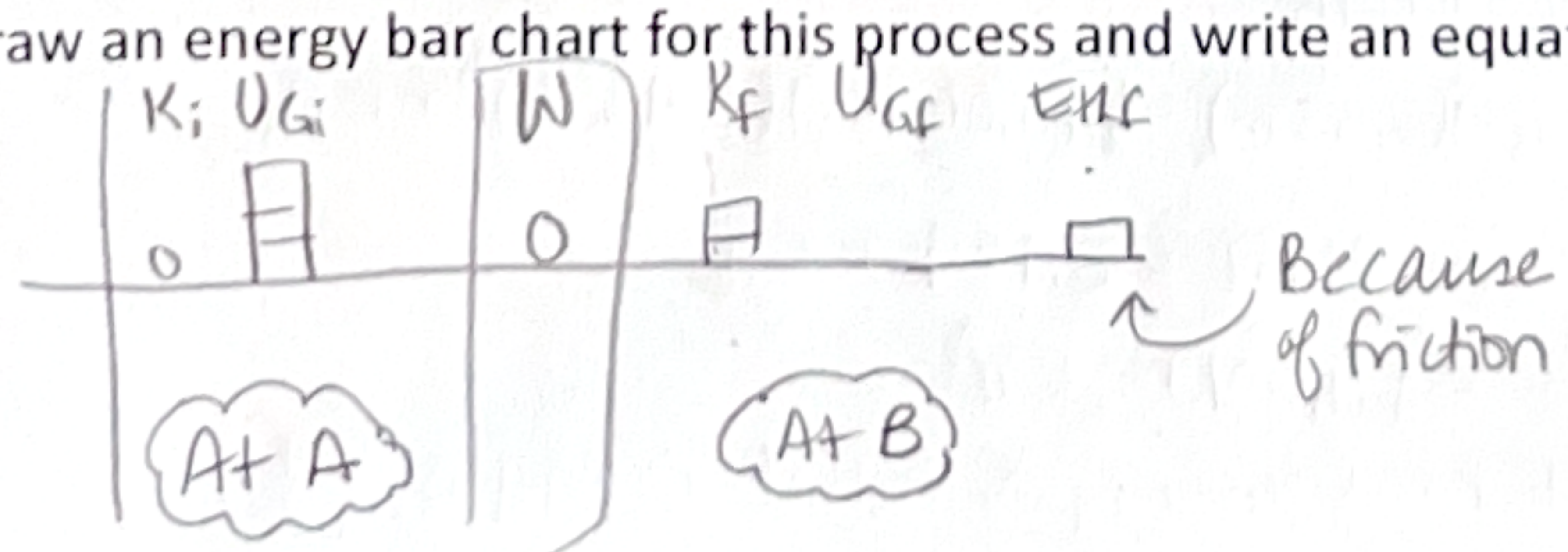
System: car, earth, track

What external forces are there on the system? table

Which, if any, external forces do work on the system? no work done by force of table because that force on track does not move through a displacement

For each external force that does work, identify the sign of the work: N/A

c. Draw an energy bar chart for this process and write an equation that represents this process.



$E_i + W_{ext} = E_f$

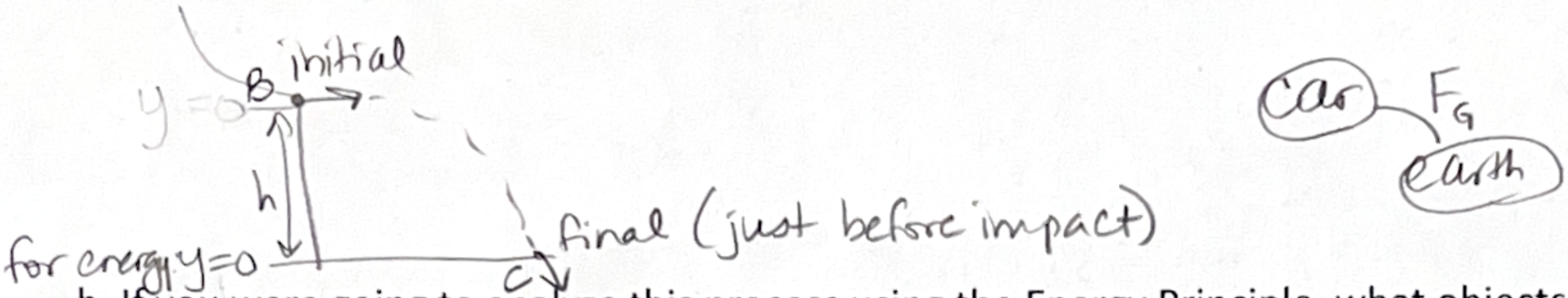
$U_{Gi} = K_f + E_{th}$

$mgh_i = \frac{1}{2}mV_f^2 + E_{th}$

Two unknowns

4. Consider the process of the **car moving through the air**

a. Make a sketch showing the initial and final moments of this process:



b. If you were going to analyze this process using the Energy Principle, what objects would you put in the system? *Try to define the system so the work done by external forces is zero.*

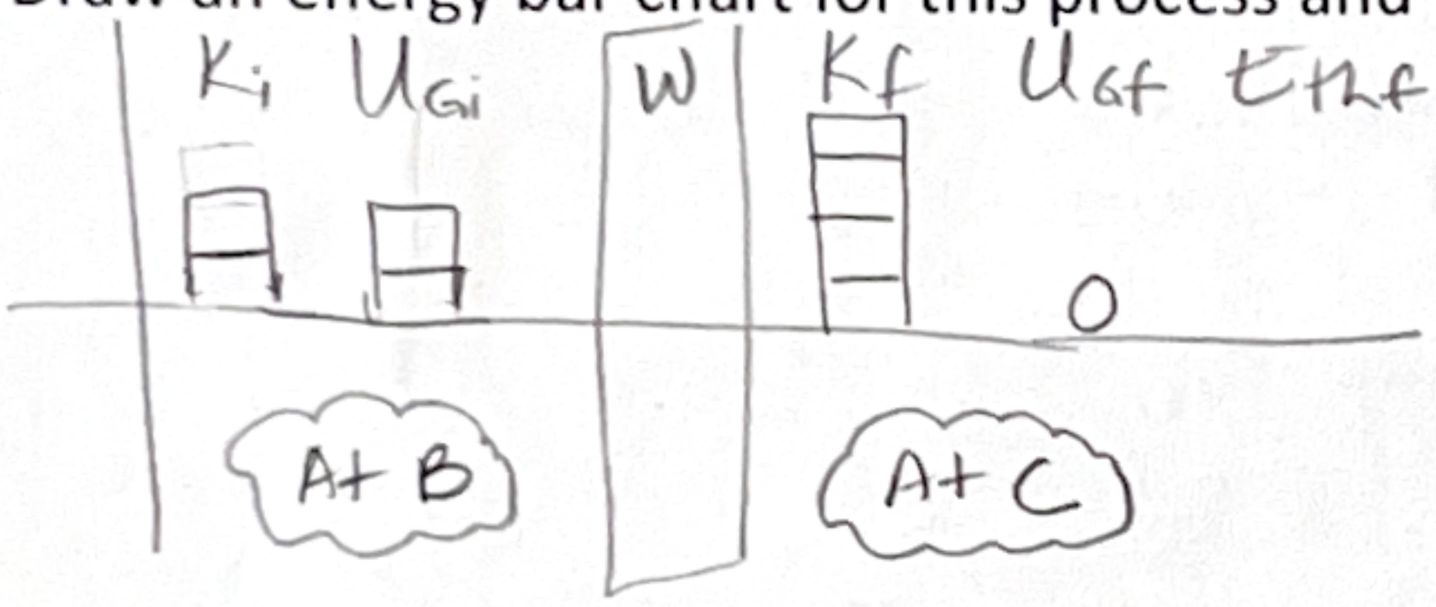
System: car, earth

What external forces are there on the system? none

Which, if any, external forces do work on the system? N/A

For each external force that does work, identify the sign of the work: N/A

c. Draw an energy bar chart for this process and write an equation that represents this process

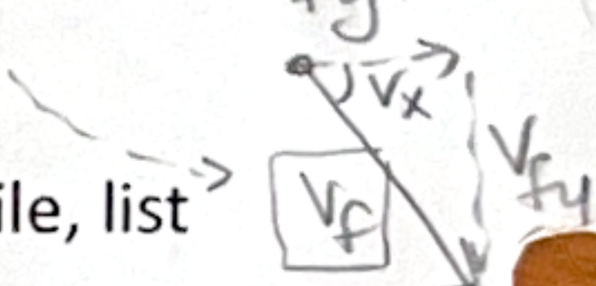


$E_i + W_{ext} = E_f$

$K_i + U_{Gi} = K_f$

$\frac{1}{2}mv_i^2 + mgh = \frac{1}{2}m\boxed{v_f^2}$

This is the final velocity before impact, not v_{fy}:



d. If you were going to analyze this process using the kinematic equations for a projectile, list the variables that might be involved, and fill in the ones that you already know:

Interval From B to C (see diagram)

Horiz	Vert
$\Delta x = 0.952m$	$\Delta y = -.754m$
$v_x =$	$v_{iy} = 0$
$\Delta t =$	$v_{fy} =$
	$g = -9.8 m/s^2$
	$\Delta t =$

5. Determine the speed of the car at the instant it left the track and began its motion in the air.

I can't find it from the 1st process because I don't have enough information. For the motion in the air, I can't use energy because I don't have enough information. But I can use Projectile motion!

$\Delta y = v_{iy}\Delta t + \frac{1}{2}a\Delta t^2$

$-0.754m = (0)\Delta t + \frac{1}{2}(-9.8 m/s^2)\Delta t^2$

$.392s = \Delta t$

$\Delta x = v_x \Delta t$

$0.952 = v_x(.392s)$

$2.43 m/s = v_x$

6. Determine the amount of energy that was converted to thermal energy as a result of the friction while the car was moving on the track

Now I can use energy for the motion on the track:

using my equation from 4c,

$mgh_i = \frac{1}{2}mv_f^2 + E_{th}$

$(0.064kg)(9.8 m/s^2)(0.35m) = \frac{1}{2}(0.064kg)(2.43 m/s)^2 + E_{th}$

$0.21952 = 0.189 + E_{th}$

$\boxed{0.031J = E_{th}}$

(Just for Fun :) The ratio of this thermal energy to initial energy is $\frac{E_{th}}{E_i} = \frac{0.031J}{.21952J} = .14 = 14\%$