
PHYS103: GENERAL PHYSICS I

NOTES

PROFESSOR DAVID JAMES

EDITED BY
TREVOR BUSHNELL

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Introduction

This document aims to highlight the important content of the PHYS103 course in traditional notes format. These notes are completely open-source, which means anyone is allowed to use these notes for their own personal benefit without having to seek permission from myself.

While these notes are designed for the PHYS103 course, all of the content seen in these notes are equivalent to a one-semester calculus-based introductory physics class taken at many universities. The content in these notes might also have some overlap with the AP Physics C: Mechanics Course. As such, students in the AP Physics C: Mechanics course and students taken any calculus-based introductory physics course might still find the content provided in these notes useful.

Due to the open-source nature of these notes, anyone is allowed to contribute to improving these notes as they see fit. Since I am using GitHub to distribute these notes easily, you must request all changes through the repository website on GitHub, which you can find **here**. If you are interested in contributing to these notes, then there are a few ways that you can do so:

1. **Open and submit an issue on my GitHub repository:** I write all my notes in \LaTeX , which is a typesetting language that is really helpful when it comes to typing and rendering math equations quickly and easily. If you do not know how to write \LaTeX code but are still interested in making a change to the notes, you can open an issue by going to the MathNotes repo on GitHub, and clicking on the button labeled "New Issue." From there, you can type out the change that you wish to see in the notes. It would be helpful if you would indicate what course you would like to see changed so that I can understand what you are referring to. I will then update the code to include your issue so that you don't have to worry about writing the code yourself.
2. **Create and submit a pull request:** If you know how to write LaTeX code and you understand how GitHub works, you can submit a pull request where you can write the code that you want to change yourself. I will then review the code and either submit the code to be incorporated into the notes OR provide some comments on your code if I wish for something to be different.

Thank you so much for using these notes. I hope that the information is provided in such a way that it can help you when reviewing content for you homework, quizzes, and exams and just in general when it comes to learning the content for the course. Happy studying!

Chapter 1

Measurement and Vectors

§1.1 Units and Unit Conversions

- In order to effectively understand the physical world around us and be able to make comparisons between physical situations, we need to be able to quantify different physical situations
- There are many different ways that we can quantify the same unit of measure, and as such it is important to know how to convert between these different measurement types
- To convert between different units, find a relationship between the two units you wish to convert and express them as a 1-to-1 ratio. If you multiply this ratio by the measurement you wish to convert, you are effectively multiplying by one (it is a 1-to-1 ratio afterall) and therefore you are not changing the value of the expression
- To find relationships between different units, feel free to use Google (however it is encouraged to see if you can commit some of these relationships to memory as the class progresses)

§1.2 EXAMPLES: Unit Conversions

The following are some examples of how to convert different units of measurement. Some of these units are completely arbitrary and are simply used to show the process for converting between different units of measurement.

Problem 1. Convert $70 \frac{\text{miles}}{\text{hour}}$ to $\frac{\text{meters}}{\text{second}}$

$$\frac{70 \text{ miles}}{\text{hour}} \cdot \frac{1.609 \text{ km}}{1 \text{ mile}} \cdot \frac{1 \text{ hr}}{3600 \text{ sec}} \cdot \frac{1000 \text{ m}}{1 \text{ km}} \approx 31.286 \frac{\text{m}}{\text{s}}$$

Problem 2. A 'gry' is $\frac{1}{10}$ of a line which is $\frac{1}{12}$ of an inch. A common length in publishing is a 'point' which is $\frac{1}{72}$ of an inch. Convert 0.5 grys^2 to points^2 .

$$\frac{0.5 \text{ grys}^2}{1} \cdot \frac{(0.1 \text{ lines})^2}{(1 \text{ gry})^2} \cdot \frac{(\frac{1}{12} \text{ inches})^2}{(1 \text{ line})^2} \cdot \frac{(1 \text{ point})^2}{(\frac{1}{72} \text{ inches})^2} = 0.18 \text{ points}^2$$

Problem 3. A lake has 120 acres of water and is 20 feet deep. How many kiloliters of water are in the lake?

Begin by first computing the volume of the lake using the units given:

$$V = (120 \text{ acres}) \cdot (20 \text{ ft}) = 2400 \text{ acres} \cdot \text{ft}$$

Now we can convert the volume to kiloliters:

$$\frac{2400 \text{ acres} \cdot \text{ft}}{1} \cdot \frac{(1.609 \text{ km})^2}{(1 \text{ mi})^2} \cdot \frac{1 \text{ mi}^2}{640 \text{ acres}} \cdot \frac{1 \text{ m}}{3.28 \text{ ft}} \cdot \frac{1 \text{ km}}{1000 \text{ m}} = 0.00296 \text{ km}^3$$

$$\frac{0.00296 \text{ km}^3}{1} \cdot \frac{1 \text{ mL}}{1 \text{ cm}^3} \cdot \frac{1 \text{ L}}{1000 \text{ mL}} \cdot \frac{(1000 \text{ m})^3}{(1 \text{ km})^3} \cdot \frac{(100 \text{ cm})^3}{(1 \text{ m})^3} \cdot \frac{1 \text{ kL}}{1000 \text{ L}} = 2.96 \times 10^6 \text{ kL}$$

Chapter 2

Kinematics

Chapter 3

Forces

Definition 3.0.1: Newton's Second Law

To calculate the **net force** that an object is experiencing, use the following equation:

$$\sum \vec{F} = m\vec{a}$$

Or using calculus:

$$\sum \vec{F} = m \frac{d\vec{v}}{dt}$$

- Many times, we will be looking at forces in 2D, which means that the net force looks like the following:

$$\sum F = F_x \vec{i} + F_y \vec{j}$$

- Since net force has two components, we can solve force problems by analyzing each component of the net force independently because **the horizontal and vertical directions are independent of each other**

Definition 3.0.2: Newton's Second Law in 2D

To find the net force of an object that is experiencing forces in multiple directions, use the following formulas:

$$\sum F_x = m\vec{a}_x$$

$$\sum F_y = m\vec{a}_y$$

Or using calculus:

$$\sum F_x = m \frac{dv_x}{dt}$$

$$\sum F_y = m \frac{dv_y}{dt}$$

§3.1 Common Forces

There are many common forces that we will talk about in physics:

- **GRAVITY:** Also called the "weight force," this force is the force that an object experiences due to gravity and can be calculated by using $F_g = mg$ where m is the mass of the object and g is the acceleration due to gravity ($9.81 \frac{m}{s^2}$ on Earth).
 - NOTE: Some people may also refer to this as the "weight force" and use F_W so be careful with notation as well as *consistent* with your notation
- **NORMAL:** The forces that the surface an object rests on. This force always acts *perpendicular* to the surface the object is resting on.
- **FRICTION:** If an object is on the ground, the frictional force is the force that always acts opposite to the direction of motion (will talk about frictional force in a later section).
- **TENSION:** The force exerted by a string or similar type of object that holds an object in place. No clear cut formula for finding this force, but drawing a free-body diagram and isolating the tension force will allow you to find the magnitude of the tension force.
- **SPRING:** The force a spring exerts on an object. Can find the magnitude of the force of a spring by using $F_s = -kx$ where k is the spring constant and x is the distance the string was stretched/compressed.
-
- **AIRDRAG:** The force of air on an object when an object is in free-fall or moving through the air.
- **CENTRIPETAL:** The force that keeps an object moving in a circle.
 - We've talked about centripetal acceleration, and if you have acceleration then you have force.

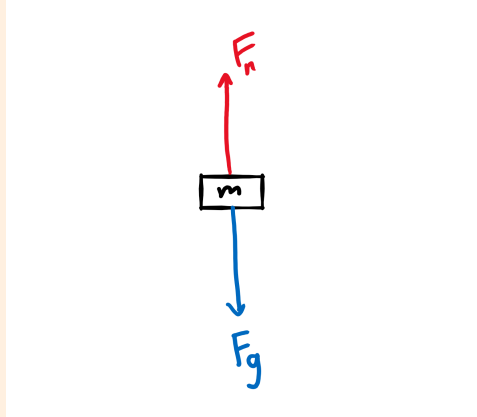
§3.2 Free Body Diagrams (FBD)

A **free body diagram** is a visual representation of all of the forces that are acting on a given object. We represent that object with a simple point and draw arrows (in the proper directions) that represent all of the forces that are acting on an object.

HOW TO DRAW A FREE BODY DIAGRAM:

1. Isolate the object of interest
2. Diagram the forces that act on the object
3. Sum the forces

Problem 4. A block with mass m is sitting on a table. Draw the FBD of the block and calculate the net force that the block experiences.



First we can algebraically analyze the forces in the x -direction. Since the object is not moving, its acceleration must be 0. There are also no forces being acted on the block in the x -direction. Therefore:

$$\sum F_x = m\vec{a}_x = 0$$

Now we can algebraically solve for the net force in the y -direction. Since the object is not moving, its acceleration must be 0. Therefore:

$$\begin{aligned}\sum F_y &= m\vec{a}_y = 0 \\ \sum F_y &= F_N - F_g = F_N - mg\end{aligned}$$

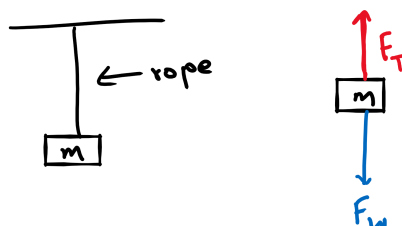
Therefore, the total net force of the block is as follows:

$$\sum F = 0\vec{i} + F_n - mg\vec{j}$$

§3.3 Other Possible Scenarios and Their FBDs

While many systems are just on the ground, there are many other physical situations where objects are hanging or on an incline. Here are some examples of FBDs of the three common scenarios of objects that are not simply on the ground:

Hanging From a Rope

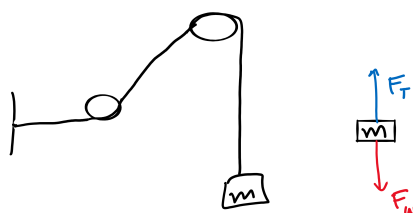


In the FBD pictured above, notice how there is no normal force because a normal force only exists if an object is resting on a surface (in this case the object is airborne). We can also solve this algebraically:

$$\begin{aligned}\sum F &= m\vec{a} = 0 \quad (\text{object is in equilibrium}) \\ \sum F_x &= 0 \quad (\text{there are no forces in the } x \text{ direction}) \\ \sum F_y &= F_T - F_g = F_T - mg\end{aligned}$$

Keep in mind that F_T is the *tension force*, which is the force that the rope pulls on the object that it is attached to.

On a Pulley



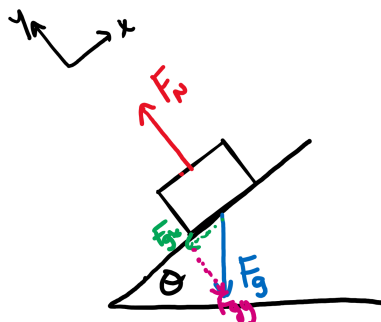
In the FBD pictured above, despite the rope changing direction multiple times across the pulley, it is still the same rope. Therefore, the tension force of the rope will be the same across the entire rope, and we can simply represent the tension force by one vector in the FBD. Algebraically solving this system results in the following:

$$\begin{aligned}\sum F &= m\vec{a} = 0 \quad (\text{object is in equilibrium}) \\ \sum F_x &= 0 \quad (\text{there are no forces in the } x \text{ direction}) \\ \sum F_y &= F_T - F_g = F_T - mg\end{aligned}$$

On A Ramp

Before drawing the FBD, it is important to note that the easiest way to solve this is to change your coordinate system to match your ramp/inclined plane. To do this, line the x-axis up with the ramp. By doing this, the acceleration is only facing in the direction of the ramp (VS having to find acceleration in both the x and y components and combining them together to find the magnitude).

The FBD looks like the following:



We can then solve this system algebraically:

$$\sum \vec{F} = m\vec{a}$$

$$\sum \vec{F}_x = -F_{gx}$$

$$-F_{gx} = m\vec{a}$$

$$-mg = m\vec{a}$$

$$\frac{-mg}{m} = \vec{a}$$

$$-g = \vec{a}$$

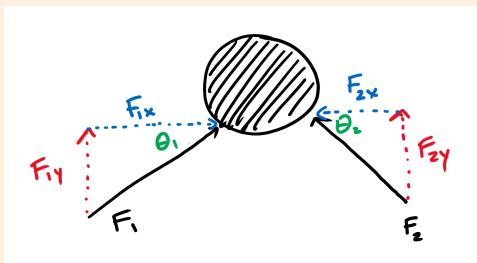
$$\sum \vec{F}_y = 0 \quad (\text{object is in equilibrium})$$

$$F_N - F_{gy} = 0$$

$$F_N = F_{gy}$$

Example Problems

Problem 5. A hockey puck experiences two forces, \vec{F}_1 and \vec{F}_2 . Find the magnitude and angle of the acceleration of the hockey puck.



$$\sum F_x = ma_x = F_1 \cos \theta_1 - F_2 \cos \theta_2$$

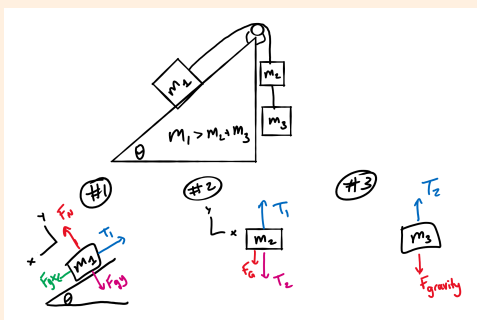
$$\sum F_y = ma_y = F_1 \sin \theta_1 + F_2 \sin \theta_2$$

$$\vec{a} = a_x \vec{i} + a_y \vec{j}$$

$$|\vec{a}| = \sqrt{a_x^2 + a_y^2}$$

$$\phi = \arctan \left(\frac{a_y}{a_x} \right)$$

Problem 6. A block of mass m_1 is attached to a pulley and sits on a slope with angle of inclination θ . Two additional masses m_2 and m_3 are hanging off the side of the slope and are also attached to the pulley. All three masses are attached to the same string. Find the tension force and the acceleration of the third block.



For #1:

$$\sum F_x = m_1 a = m_1 g \sin \theta - T_1$$

$$\sum F_y = 0 = F_N - m_1 g \cos \theta$$

For #2:

$$\sum F_y = m_2 a = T_1 - T_2 - m_2 g$$

For #3:

$$\sum F_y = m_3 a = T_2 - m_3 g$$

§3.4 Frictional Force

Definition 3.4.1: Frictional Force

There are two different types of frictional forces:

- **STATIC FRICTION:** A frictional force that is opposing the object when a force is applied to an object, but an object is not moving. The magnitude of this force *changes with the magnitude of the force being applied*.

$$F_f \leq \mu_s F_N$$

INSERT A GRAPH HERE

- **KINETIC FRICTION:** A frictional force that opposes the object while the object is in motion. This force *remains constant*.

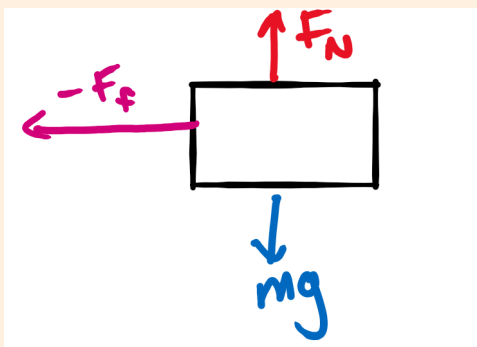
$$F_f = \mu_k F_N$$

In all cases, μ is the coefficient of friction (which is a constant that varies depending on the surface that the object is on).

Another thing to note is that $\mu_k < \mu_s < 1$.

If the system is at rest or has no acceleration, use **static coefficient of friction**. If the system is accelerating, use the **kinetic coefficient of friction**.

Problem 7. A car is traveling at a velocity of $1.6 \frac{m}{s}$ with a mass of 1500 kg for a distance of 50 m. Assume that the acceleration is constant. Find the coefficient of kinetic friction.



First, find the sum of the forces in the y -direction:

$$\begin{aligned}\sum F_y &= 0 \\ F_N - mg &= 0 \\ F_N &= mg\end{aligned}$$

Now, find the sum of the forces in the x -direction:

$$\begin{aligned}\sum F_y &= ma \\ -F_f &= ma \\ \mu_k F_N &= ma \\ \mu_k mg &= ma \\ \mu_k &= -\frac{a}{g}\end{aligned}$$

Using kinematics equations, we can solve for a :

$$\begin{aligned}v_f^2 &= v_i^2 + 2a\Delta x \\ a &= \frac{v_f^2 - v_i^2}{2\Delta x} \\ a &= \frac{(0 \frac{m}{s})^2 - (1.6 \frac{m}{s})^2}{2 \cdot 50 \text{ m}} \\ a &= -7.7 \frac{m}{s^2}\end{aligned}$$

Now, we can solve for μ_k :

$$\begin{aligned}\mu_k &= -\frac{a}{g} \\ \mu_k &= -\frac{-7.7 \frac{m}{s^2}}{9.8 \frac{m}{s^2}} \\ \mu_k &= \text{ANSWER}\end{aligned}$$

§3.5 Air Drag

Definition 3.5.1: Air Drag

$$F_{AD} = \frac{1}{2}C\rho A|v|^2$$

C = coefficient of "air" friction

ρ = the density of the air

A = the cross-sectional area of the object

v = the velocity of the object (SCALAR QUANTITY)

Problem 8. A bowling ball with mass of 5 kg and radius of 4 cm falls through the air with a C value of 1.2 and air density of $1.23 \frac{\text{kg}}{\text{m}^3}$. What is the terminal velocity of the bowling ball?

$$\begin{aligned}\sum F_y &= 0 = F_{AD} - mg \\ F_{AD} &= mg \\ \frac{1}{2}C\rho Av^2 &= mg \\ v &= \sqrt{\frac{2mg}{C\rho A}} \\ v &= \sqrt{\frac{2(5 \text{ kg})(9.81 \frac{\text{m}}{\text{s}^2})}{(1.2)\left(1.23 \frac{\text{kg}}{\text{m}^3}\right)(0.04 \text{ m})^2\pi}} \\ v &\approx 115 \frac{\text{m}}{\text{s}^2}\end{aligned}$$

§3.6 Centripetal Forces

- Recall that $a_{\text{centripetal}} = \frac{|v|^2}{R}$
- A **centripetal force** is any force that causes a system to begin rotating in a circle
- You would still use Newton's second law, but the acceleration used in Newton's Second Law will be the *centripetal acceleration*

Problem 9. You are riding on a ferris wheel and your mass is 50 kg. The radius of the ferris wheel is 25 m. You go around the ferris wheel at a rate of 1 revolution per minute. Find F_N a) at the bottom of the ferris wheel and b) at the top of the ferris wheel.

a) (top)

$$\begin{aligned}\sum F_T &= ma_c = -N_T + mg \\ m\left(\frac{|v|^2}{R}\right) &= -N_T + mg \\ N_T &= mg - \frac{mv^2}{R}\end{aligned}$$

b) (bottom)

$$\begin{aligned}\sum F_B &= ma_c = N_B - mg \\ N_B &= m\left(g + \frac{v^2}{R}\right)\end{aligned}$$

Problem 10. A car with mass m is going around a turn on an inclined plane inclined at an angle θ . **DRAW A FBD** and determine the friction force being applied.

Sum of the forces in the y -direction:

$$\begin{aligned}\sum F_y &= ma_y = F_N - mg \cos \theta \\ \sum F_y &= ma \sin \theta = F_N - mg \cos \theta \\ F_N &= m \left(\frac{v^2}{R} \sin \theta - g \cos \theta \right)\end{aligned}$$

Sum of the forces in the x -direction:

$$\begin{aligned}\sum F_x &= ma_x = F_f + mg \sin \theta \\ \sum F_x &= ma \cos \theta = F_f + mg \sin \theta \\ F_f &= m(a \cos \theta - g \sin \theta) \\ F_f &= m \left(\frac{v^2}{R} \cos \theta - g \sin \theta \right) \\ \mu F_N &= m \left(\frac{v^2}{R} \cos \theta - g \sin \theta \right)\end{aligned}$$

NOW GO BACK AND TRY THIS PROBLEM AGAIN BUT WITHOUT TILTING THE AXES AND PUT THIS INTO YOUR NOTES

Problem 11. If the static coefficient of friction is 0.7, then how fast can a 5 m merry-go-round spin by your side.

$$\begin{aligned}\sum F_y &= 0 = F_N - mg \\ F_N &= mg \\ \sum F_x &= ma = F_f \\ \mu_s F_N &= ma \\ \mu_s mg &= ma \\ \mu_s g &= \frac{v^2}{R} \\ v &= \sqrt{\mu_s g R}\end{aligned}$$

Chapter 4

Work and Energy

§4.1 Introduction to Work

Definition 4.1.1

WORK: How much energy it takes to do a certain physical action.

$$W = \Delta E = \vec{F} \cdot \vec{\Delta x}$$

W = Work done (SI Units: J = N m)

ΔE = Change in energy

\vec{F} = the force applied

Δx = the displacement over which the object was applied the given force \vec{F}

Problem 12. A couch is pushed with a force 25 N over a distance of 5 m. Calculate the work that is applied to the couch.

$$W = F_A \cdot \Delta x$$

$$W = (25 \text{ N})(5 \text{ m})$$

$$W = 100 \text{ J}$$

Problem 13. SEE ATTACHED FIGURE

- a) How much energy is expended by the applied force to move the couch 5 m?
b) How much energy does the frictional force expend to move the couch 5 m?

To solve part a):

$$W_A = F_{Ax} \cdot \Delta x$$

$$W_A = F \cos \theta \cdot \Delta x$$

$$W_A = (50 \text{ N}) \cos(25^\circ)(5 \text{ m})$$

$$W_A = 227 \text{ J}$$

To solve part b):

$$W_f = -F_f \cdot \Delta x$$

$$W_f = -\mu_k F_N \cdot \Delta x$$

$$W_f = -\mu_k (mg + F_A \sin \theta) \cdot \Delta x$$

$$W_f = -(0.15)((20 \text{ kg})(9.81 \frac{\text{m}}{\text{s}^2}) + (50 \text{ N}) \sin(25^\circ))W_f = \text{VALUE}$$

§4.2 Energy

Energy comes in many different forms. The main forms of energy (as well as the proofs to get their respective equations) are listed below:

Definition 4.2.1: Kinetic Energy

If an object is moving, the energy that the object expends is equal to the **kinetic energy**.

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

KE = the kinetic energy expended

m = mass of the object

v = velocity of the object at the given moment where you wish to find the energy

Proof. PROOF OF KINETIC ENERGY HERE ■

Definition 4.2.2: Potential Energy

$$PE = mgh$$

Proof. PROOF OF POTENTIAL ENERGY HERE ■

Definition 4.2.3: Spring Energy

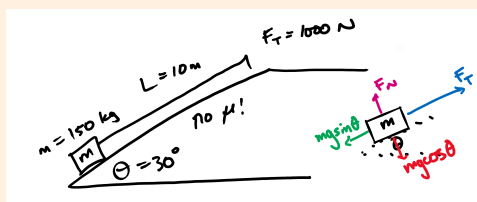
$$SE = \frac{1}{2}kx^2$$

Proof. PROOF OF SPRING ENERGY HERE ■

§4.2.1 The Usefulness of Energy and Work

While we have an equation for the work if we know the applied forces, if we know other elements about the system (how fast) [FINISH THIS LATER]

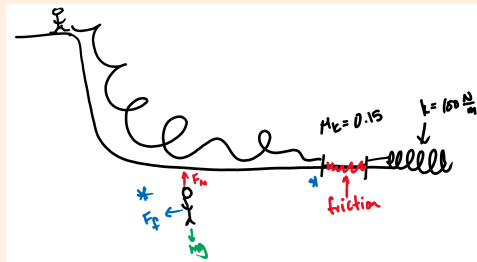
Problem 14. ADD PROBLEM TEXT LATER



While this problem could be solved using kinematics and Newton's second law, we can also use the Work-Energy theorem.

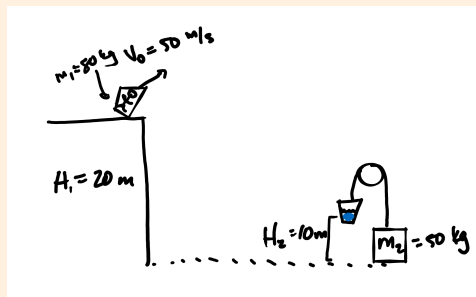
$$\begin{aligned}
 W_{in} &= \Delta KE + \delta PE \\
 F_T \cdot L &= \frac{1}{2}m(v_f - v_i)^2 + mg(h_f - h_i) \\
 F_T \cdot L &= \frac{1}{2}mv_f^2 + mgh_f \\
 v_f &= \sqrt{\frac{2(F_T L - mgh_f)}{m}} \\
 v_f &= \sqrt{\frac{2(F_T L - mg(L \sin \theta))}{m}}
 \end{aligned}$$

Problem 15. A skier starts at the top of a mountain and is attached a spring at the bottom of the cliff. The skier will also experience friction for 15m at the bottom of the slope right before the spring. How far was the spring compressed when the skier reaches the bottom of the slope?



$$\begin{aligned}
 W_{in} &= 0 = \Delta PE + \Delta E_s + \Delta E_T \\
 0 &= mg(h_f - h_i) + \frac{1}{2}k(x_f - x_i)^2 + \mu_k mgD \\
 0 &= -mgh_i + \frac{1}{2}kx_f^2 + \mu_k mgD \\
 x_f &= \sqrt{\frac{(mgh_i - \mu_k mgD)^2}{k}} \\
 x_f &= \sqrt{\frac{((70 \text{ kg})(9.81 \frac{\text{m}}{\text{s}^2})(50 \text{ m}) - (0.15)(70 \text{ kg})(9.81 \frac{\text{m}}{\text{s}^2})(15 \text{ m}))^2}{150 \frac{\text{N}}{\text{m}}}}
 \end{aligned}$$

Problem 16. A stunt artist was launched out of a cannon on a 20m pedestal. He will land in a bucket attached to a pulley. The pulley also has a 50kg mass attached to it, and the bucket is 10m above the ground. Assume the bucket has no mass and the pulley exerts no friction on the string wrapped around the pulley. What is the speed of the stunt artist right when he lands in the bucket?



$$W = 0 = \Delta KE_1 + \Delta PE_1 + \Delta KE_2 + \Delta PE_2$$

$$0 = \frac{1}{2}m(v_{f1} - v_{i1})^2 + \frac{1}{2}m_2(v_{f2} - v_{i2})^2 + m_1g(H_{f1} - H_{i1}) + m_2g(H_{f2} - H_{i2})$$

$$\text{ANSWER: } 41.3 \frac{\text{m}}{\text{s}}$$