University Physics I
Instructor Manual

ETAMU Department of Physics and Astronomy

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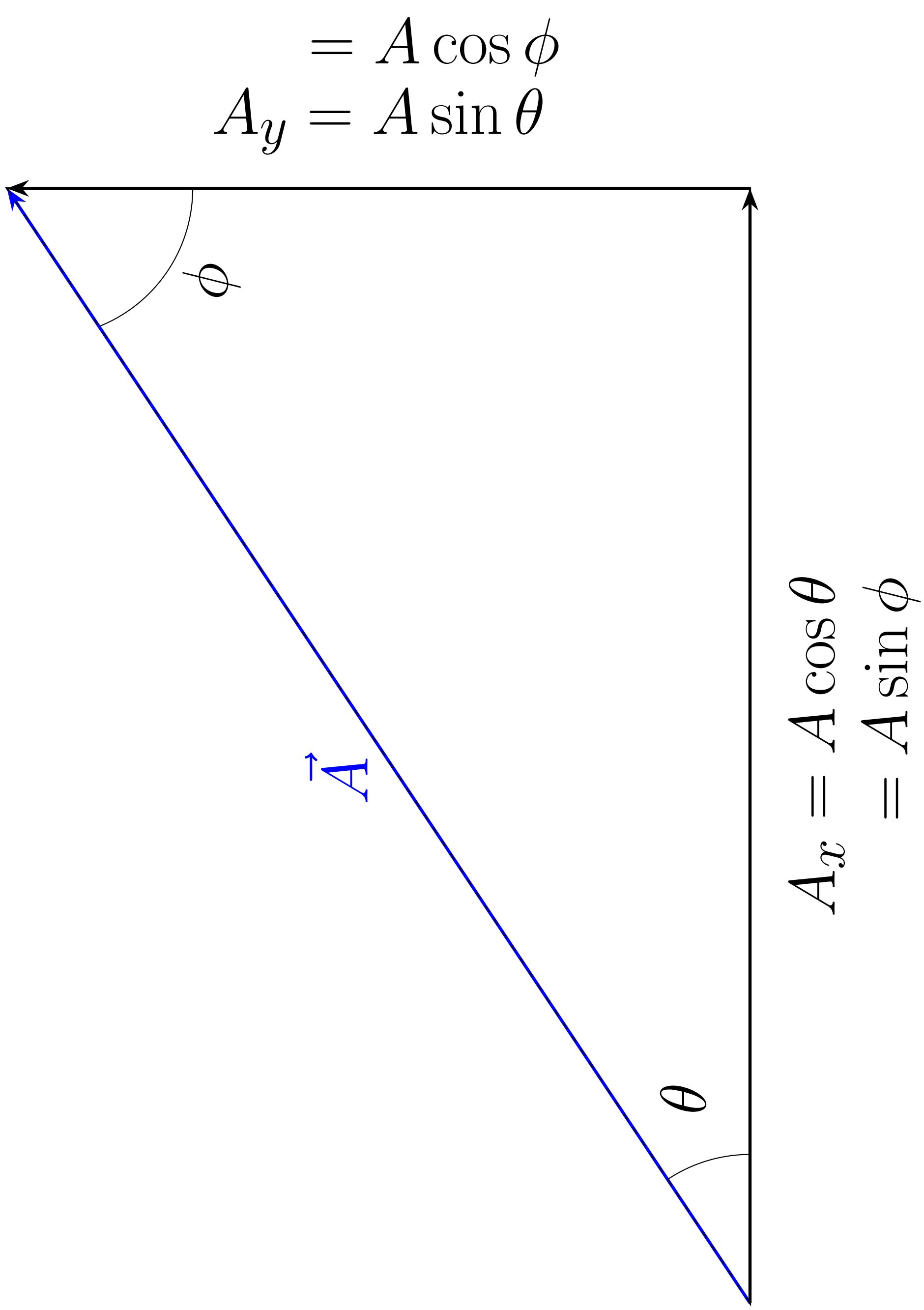

Right Triangle with Angles θ and ϕ

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Preface

This is the instructor manual for ETAMU's University Physics I (PHYS 2425) studio-mode course. This manual is intended to be used as a guide for instructors teaching the course, as well as undergraduate learning assistants (LAs) and graduate teaching assistants (TAs) who may be helping to facilitate the course.

In this manual, you will find brief descriptions of each assignment students will complete in class, as well as additional details about each assignment that may be helpful for instructors. This includes tips for facilitating group work, common student misconceptions, and additional resources for instructors.

This manual is not intended to be used as a solution manual. First, if this manual were to be released to students, we would need to re-write all the problems to ensure students are not simply copying answers. Second, the best way to really understand the problems is to work through them yourself. This will help you better facilitate group work and guide students to the correct answers. In a few cases, a specific solution is provided to illustrate an important point, but in general, you should work through the problems yourself.

If you have any questions or feedback about this manual, please feel free to reach out to the ETAMU Physics Department. This manual is written in LaTeX, and the source files are available on GitHub, link below.

https://github.com/Blake-Head/ETAMU-Physics.git

While it goes without saying, please do not share this manual or any of its contents with students. Doing so would seriously undermine the integrity of the course. If you are an instructor, TA, or LA for the course, please keep this manual private.

0.1 Ordering of Topics

The ordering of topics in this course is not set in stone. The following is a suggested order that has been found to work well. However, you may find that a different order works better for you and your students. Feel free to adjust the order as needed.

1. **Momentum and Impulse** (About 3 Weeks)
   - Momentum and Impulse
   - Momentum Conservation
   - Vectors
2. **Dynamics** (About 4 Weeks)
   - Newton's Laws
   - Free Body Diagrams
   - Friction
   - Uniform Circular Motion
3. **Work and Energy** (About 3 Weeks)
   - Work Energy Theorem
   - Work from Constant and Varying Forces
   - Conservation of Energy
4. **Kinematics** (About 4 Weeks)
   - Displacement, Velocity, Acceleration
   - Motion with Constant Acceleration
   - Problem Solving with Kinematics
5. **Rotational Motion** (About 2 Weeks)
   - Torque
   - Angular Momentum and Moment of Inertia
   - Rotational Kinematics

If you are from the future, you may note the lack of sections on thermodynamics, fluids, and waves. These sections have been intentionally left out of this course, as they are typically covered in other courses. If you have time to include more material, thermodynamics is a good choice.

A Note on Ordering

This ordering is chosen as, at the time of writing, University Physics 1 requires Calculus 1 as a co-requisite. This means that students will be learning about derivatives and integrals for the first time while taking this course. The ordering above allows students to learn about momentum and impulse first, which can be done with only algebra. This allows students to get comfortable with the studio format and group work before being introduced to more mathematically complex topics.

That being said, one could easily introduce the concept of simple derivatives and integrals up front. The most complex calculus needed is the ability to integrate / differentiate polynomials. There are a few example problems that ask for exponentials and trigonometric functions, but these are primarily for practice and can be easily skipped.

Given the structure of all the course materials, none assume prior knowledge of the previous section(s), which as a physicist you likely know is because most of this is just momentum conservation in disguise. Each module can, for the most part, be taught independently of the others. Of course, use your own judgment and adapt as needed.

Chapter 1

Momentum and Impulse

The first section of this class typically covers momentum, impulse, and conservation of momentum. For reference, these three ideas are given below in mathematical form.

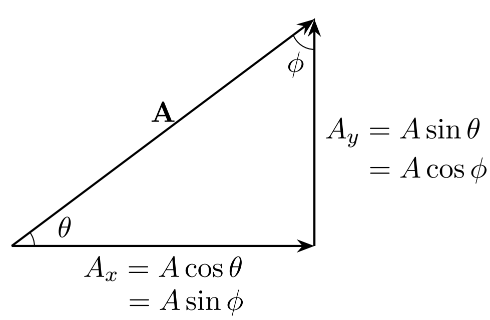
$$\mathbf{p} = m\mathbf{v} \qquad \text{(Momentum)}$$

$$\mathbf{J} = \Delta\mathbf{p} = \mathbf{F}_{\text{avg}}\Delta t \qquad \text{(Impulse)}$$

$$\sum \mathbf{p}_{\text{initial}} = \sum \mathbf{p}_{\text{final}} \qquad \text{(Conservation of Momentum)}$$

All problems in this section can be solved only with the above equations! Take careful note that the conservation of momentum condition is a *vector* sum! Also take note of the impulse equation used here. This form is only valid for a constant force. Calculus 1 is a co-requisite for this course, so at this point student will likely not be familiar or comfortable with the idea of an integral.

In addition to these equations, you will also need to know how to break vectors into components, since we will be dealing with some two-dimensional problems. The most important picture for knowing how to accomplish this is shown below.



Right Triangle Representation of Vector

If you are teaching this course, you will be explaing this diagram **very** frequently. Make sure you understand it well, and can explain it clearly to students! We have included a large format version of this same picture on the first page for easy reference. Trust us, you'll need it.

1.1 Momentum Tutorial 1: Oomph

Approximate Time: 50 minutes
Equipment Needed: None
Pre-Lecture Required?: No

This introductory tutorial is meant to do two things: (1) introduce students to the idea of momentum and impulse, and (2) get students used to studio mode and working in groups (assuming this is the first assignment of the semester).

The tutorial introduces the concept of momentum under the guise of **"oomph"** (a non-technical term for momentum). The students are asked to make qualitative predictions about the oomph of various objects of different masses and speeds. Ideally, the students will come to the conclusion that oomph is proportional to both mass and speed, and that the mathematical expression for oomph is $p = mv$.

The second section of the tutorial introduces the idea of impulse, and how a force acting over a time interval can change an object's momentum. The students are asked to make qualitative predictions about how the change in momentum depends on the force applied to an object and how long it is applied for. Ideally, the students will come to the conclusion that the change in oomph is proportional to both the force and the time interval, and that the mathematical expression for impulse is $J = F\Delta t$.

At this stage, it is enough that students understand what these two concepts are. You will note that none of the equations are written in vector form. This is intentional, as we will introduce the vector nature of momentum and impulse in the next tutorial. For now, we want students to get comfortable with the concepts in one dimension.

Student Issue 1: Forces over Time

A common issue that students have is believing that applying a force over 5 seconds and applying the same force over 10 seconds both result in the same momentum in the end. It is often because students operate under a sort of "maximum" force idea, where they are thinking about *themselves* pushing the object. Since a person has a maximum force they can apply (and because friction and other things exist), in reality you can really only speed things you're pushing up to a certain point, so time doesn't seem to matter. A good example to use in these cases are rocket ships in space.

Learning Outcomes: Oomph

(a) Momentum is a measure of mass in motion and is calculated by $p = mv$.

(b) Impulse is a measure of an object's **change** in momentum, and is calculated by $J = F\Delta t = \Delta p$.

(c) Group work and discussions should be written out clearly on whiteboards.

1.2 Momentum Problem Set 1: Impulse in One Dimension

Approximate Time: 50 minutes
Equipment Needed: None
Pre-Lecture Required?: Yes - Area under the curve integration

Each of these problems can be solved by first finding the impulse, either by using $J = F\Delta t$ for constant forces, or by finding the area under the curve for variable forces, in which cases a graph is provided.

Problem 1: A 50.0 kg archer, standing on frictionless ice, shoots a 100.0 g arrow at a speed of 100.0 m/s. The direction that the arrow travels is defined to be the positive direction.

(a) What is the sign of the impulse (positive or negative)imparted to the arrow?

(b) What magnitude impulse did the archer impart to the arrow?

(c) Estimate (just make a guess, .1 s, .5 s, 2 s, etc.) how much time the string on the bow was in contact with the arrow.

(d) Calculate the force the bow string imparted on the arrow.

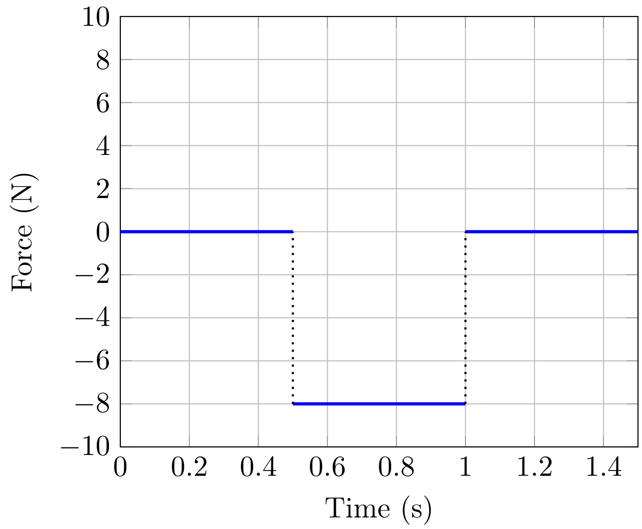
Student Issue: Guessing Values

You'd be surprised how often students don't realize that making an educated guess about how long the bowstring is in contact with the arrow is a perfectly acceptable thing to do. If students are struggling with this, remind them that they are not being asked to calculate the exact force, just to estimate it.

Problem 2: A miniature sled with a mass of 8.0 kg is sliding across the ice to the right with a speed of 2.0 m/s when it hits a rough patch in the ice. The force of friction for this rough patch of ice is shown as a function of time in the figure below. To the right is defined to be positive direction.

(a) How will the sled's speed change during the rough patch? Explain how your intuitive answer compares to the information given in the graph.

(b) Calculate the sled's speed and direction after the rough patch. Explain how this answer compares to your intuition.



Student Issue: Negative Area

Take note that the area under the curve here is negative, since the force is negative. While students typically do in fact correctly state that the impulse is negative here, it often comes purely from a physical intuition standpoint (friction slows things down), and they don't actually calculate the area numerically, with the negative 8 Newton force.

Student Issue: Step Functions

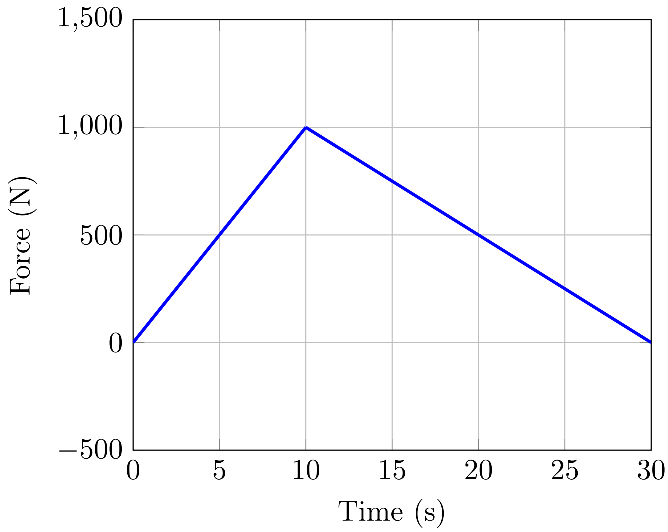
A handful of students will argue about the nature of the force graph here. They will say that the force can't just instantaneously jump from 0 to -8 N, and then back to 0 N. Try to keep them on the critical moments here, not the transition points. Assure them that this graph is an **idealized** representation to help focus on the key concepts.

Problem 3: Far in space, where gravity is negligible, a 425 kg rocket traveling at 75 m/s fires its engines. The figure shows the thrust force as a function of time. The mass lost by the rocket during these 30.0 s is negligible. Up is defined to be the positive direction.

(a) Describe how the rocket's speed changes in the time intervals (i) 0-10 s and (ii) 10-30 s.

(b) Calculate the rocket's speed at 10 s and at 30 s.

(c) Are your answers to (a) and (b) consistent? If not, explain how you would change your answers to make them consistent.



Student Issue: Negative Slope ≠ Slowing Down

A very common mistake made on this problem is that during the first 10 seconds, the rocket is speeding up, which is true. However, students will then go on to say that the rocket is slowing down during the next 20 seconds, which is not true. The force here is **always** positive, meaning the rocket is always speeding up. The force is just not as large during the second time interval, so the rocket is still speeding up, just not as quickly.

Problem 4: A monkey throws a lime. The lime has a mass of 0.3 kg and it is thrown at an initial velocity of 80 m/s (this particular monkey has realized there are no limits to monkey strength). The lime flies across the jungle until it hits MonkeyMan Steve in the face. It is in contact with his face for 0.5 s. What is the force felt (in Newtons) by poor poor MonkeyMan Steve?

Learning Outcomes: Impulse in One Dimension

(a) Calculate impulse from a force vs. time graph.

(b) Calculate final velocity from impulse and initial velocity.

(c) Understand that a negative force results in a negative impulse.

(d) Solve problems algebraically and numerically.

Chapter 2

Dynamics

This is the first experiment chapter. Add your content here.

2.1 Energy and Work

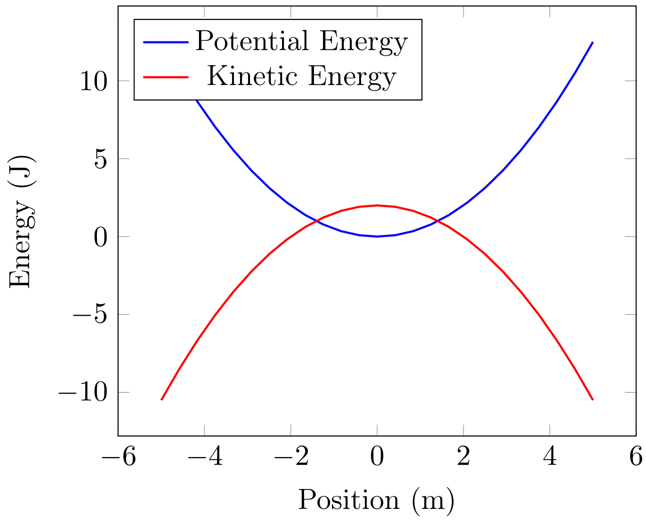
The work-energy theorem states that the work done on an object equals its change in kinetic energy:

$$W = \Delta KE = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

Creating Energy Diagrams

Use PGFPlots for energy graphs:

```
\begin{tikzpicture}
\begin{axis}[
    xlabel={Position (m)},
    ylabel={Energy (J)},
    legend pos=north west
]
\addplot[blue,thick] {x^2/2};
\addlegendentry{Potential Energy}
\addplot[red,thick] {2-x^2/2};
\addlegendentry{Kinetic Energy}
\end{axis}
\end{tikzpicture}
```


Potential Energy
Kinetic Energy
Energy (J)
Position (m)
10
5
0
−5
−10
−6
−4
−2
0
2
4
6

Chapter 3

Work and Energy

Content to be added here.

Chapter 4

Kinematics

content to be added here.

Chapter 5

Rotational Motion

Content to be added here.