1 Physics that you should know

1.1 Introduction

This course is intended for people with little or no prior formal exposure to physics. The basic ideas and the relevant definitions will all be introduced as they are required. This does not mean that some background is not helpful. Prior exposure to physical reasoning and to the vocabulary should make the material a little more accessible. Some concepts such as energy that we all use and discuss in our daily lives are more refined in the context of physics and also in this course. But even in these cases, the ideas are only needed in the most general sense. More important than a background in physics is experience with consistent logical reasoning and a curiousity about the world.

In particular, it is important that you have a quantitative understanding of the phenomena about us. When you discuss things that you see, you should use specific terms such as density and speed and understand what they mean. Basic mathematical concepts such as area and volume are essential. There is an extended discussion of the mathematical requirements is in “Matheatics that you should know.” All the items in the “Things that Everyone Should Know” list, should be familiar. Simple excercises like computing a route for a trip are important skills. Many of these are skills like those required for Fermi problems that are an important part of this course.

Despite this, in the following, I will outline some of the important ideas that any student in this course should know. If you do not know them and you feel that you will have difficulty, you should work with someone to get a basic understanding at the level described here.

1.2 Kinematics

You should know how to identify where a place is in a three dimensional space. You should realize that this descriptor of place is a vector quantity and that a vector has a magnitude and a direction. Vectors can be added to produce new vectors and they have simple addition rules. Two displacements can be combined and the result is a displacement. The magnitude of a vector is its length. The magnitude of the displacement is the distance, actually the shortest distance of many distances between the places that are the initial and final places that make up the displacement.

Velocity is the time rate of change of displacement. It is also a vector and the length is the speed. Velocities can be added by the same rule of tip to tail addition used for displacement. Note that if you change the displacement in any way you have a non zero velocity. Even, if you do not change the distance but change just the direction, you have a velocity.

Acceleration is the time rate of change of velocity. It is also a vector. Accelerations can be added by the same rule of tip to tail addition used for displacement and velocity. Note that if you change the velocity in any way you have a non zero acceleration. Even, if you do not change the speed but change just the direction, you have an acceleration.

It should be obvious that, if you know the position of an object, you know the velocity and the acceleration. You should also realize that, if you know the acceleration, the initial position,and the initial velocity, then you know the position for all subsequent times.

Any description of motion depends on a choice of a reference frame from which all displacement, velocity, and acceleration measurements are made.

1.3 Dynamics

Dynamics is the study of the causes of motion. A primary notion is that there are forces. These represent the effect of other bodies on the body whose motion is under study and the definition that you were taught in the third grade that a force is a push or a pull is as good as any for a start. Force is a vector quantity and obeys the usual rules for addition.

The rest of basic dynamics is contained in Newton's three laws. The first law states that, if a body has no net forces acting on it, there exists a reference frame in which the body is and remains at rest. The more usual statement of this law is that if a body has no net forces it maintains its state of motion. In order to state the second law, we need the concept of mass. For our present purposes, we can take the definition to be simply that it represents the amount of matter there is. We will spend considerable time in this course clarifying the idea of mass. Newton's second law states the a body responds to the presence of an unbalanced force by accelerating. The acceleration is the net force divided by the mass of the body. The third law states that, if two bodies exert forces on one another, these forces are equal and opposite. This law is also known as the law of action reaction.

It is very important to realize that, if you know the forces acting on a body either as a function of position or time, and you know the initial position, and velocity, you know the subsequent motion.

It is important to know several simple examples of forces. There are two types, basic and phenomenological. Basic forces are those that we attribute to the fundamental aspects of matter such as electric charge and gravitation. The phenomenological forces are due to very complex involvement of many things but, despite the complications, are simple to describe.

Examples of phenomenological forces are the normal force that stops my hand from moving through the table when I lean on it. In this case, the atoms of my hand and the atoms of the table act to produce whatever force is necessary so that my body is supported. Another example is the Hook's Law spring. Here a complicated structure of coiled metal if it is deformed produces a force. In this case, the force is proportional to the stretch of the spring, $\vec{F} = -k\vec{x}$.

There are four basic forces: strong, weak, electromagnetism, and gravitation. You should know about these forces and the simplest forms of the two classical forces: the electrical force between two charges, $\vec{F_{12}} = \frac{1}{4\pi\epsilon_0}\frac{Q_1Q_2}{|\vec{r_2}-\vec{r_1}|^3} \times (\vec{r_2} - \vec{r_1})$ and the gravitational force between two masses, $\vec{F_{12}} = -G\frac{m_1m_2}{|\vec{r_2}-\vec{r_1}|^3} \times (\vec{r_2} - \vec{r_1})$. Here $\frac{1}{4\pi\epsilon_0}$ and G are fundamental constants of nature.

From the forces and kinematics almost all of physics can be developed. Certain derived concepts are so important that they take on a fundamental nature. Ideas like work done by a force which is the force times the distance through which the force moves and kinetic energy which is the energy of motion and for slow moving particles is $\frac{m\vec{v}^2}{2}$ where $\vec{v}$ is the velocity. For special cases, there is an energy of position called the potential energy.

There are two types of momentum, quantity of motion: linear which is usually $m\vec{v}$ and rotational which is usually $mr\omega$ where r is the distance from the axis and ω is the angular speed.

You should be aware of the famous conservation laws such as energy and momentum. There are two forms for the law of conservation of energy. The equivalence of work and the total energy made up of the kinetic and potential energy. The is also a related energy conservation law that comes from thermodynamics. Here the energy is not only mechanical energy but also thermal energy and involves concepts like temperature.