PHY 121

Mechanics for Scientists and Engineers

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Homepage for our course:

http://www.pas.rochester.edu/~rajeev/PHY121.html

Lecture 1

What is Mechanics?

• Physics is the oldest and the most fundamental of all the Sciences. Mechanics is the oldest and the most fundamental part of Physics. All of Physics is modelled on Mechanics.

•Mechanics is the study of the movement. Whenever anything moves, it does so under the laws of mechanics.

•Newton formulated mechanics in terms of three very simple laws. Nobody could have just guessed these laws: they were arrived at by experiment, observation and measurement.

Calculus

•A natural language such as English is a good way of describing how people behave. A computer language such as $C++$ or BASIC describes how computers function. The laws of nature are best described using Mathematics.

The language of Nature is Mathematics.
The language of Mechanics is Calculus.

Measurement and Units

•Almost all quantities we will encounter in Physics will be measured in some unit. The basic units are those of Time, Length and Mass.

•The most familiar unit of time is a Day. Originally, it was defined as the time it takes for the Earth to make one rotation on it axis. The hour, minute and second can then be defined in terms of the day: 24 hours make a day, 60 minutes make an hour and 60 seconds make a minute.

•But the earth wobbles a little bit: it is not an accurate enough ‘clock’ for modern scientific purposes.

The Measurement of Time

•Any regular periodic process can be used to measure time. The more regular (stable) it is the more accurately it will measure time. The revolution of the satellites of Jupiter, the oscillation of a pendulum, the vibration of a quartz crystal in a wrist watch, have all been used to measure time.

•The most regular process we know of is the vibration of an atom: atoms are the best clocks. Then everyone else can synchronize to these atomic clocks. The United States Naval Observatory is responsible for maintaining the standard atomic clocks for the United States. There is no one ‘standard clock’. It is much more accurate to take the average of several clocks. Look them up at http://tycho.usno.navy.mil/time.html

The Definition of a Second

•It makes sense to use atomic vibrations to also define the unit of time, since our most accurate clocks use these vibrations to keep time. Here is the official definition of one second from the NIST webpage: the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium atom"'

•This will change as technology improves and we develop even better clocks.

•There are several systems of units used by scientists (cgs, mks etc.) but in all of them the basic unit of time is a second. Obviously an hour is 3600 seconds, a day is $24 \times 3600 =$ 86400 seconds, and so on. You can use any unit that is convenient to you as long as you know how to convert it into seconds.

Unit of Length

•The widely accepted system of units in scientific literature is the *Systeme Internationale* or *SI*. It is also known as the metric system. The basic unit of *length* is the *meter*.

•A *meter* is about equal to a *yard* or *three feet*. More precisely a *yard* is defined to be 0.9144 m.

•The meter used to be defined as 10^{-7} of the distance from the north pole to the equator of the Earth. But this turns out not to be accurate or convenient enough for modern scientific needs. As in the case of the unit of time we need a definition a physicist can use in a laboratory.

The Definition of a meter

•A basic law of physics is that *the velocity of light in a vacuum is a constant.* Light travels the same distance in the vacuum in a given time no matter where you are. Nothing else has this remarkable property. (Well, nothing else you can easily use... Can anyone name another particle that travels at the speed of light?)

•Once we have a definition of a *second* we can define the distance light travels (in the vacuum) in a given number of seconds to be the *meter*. We just have to pick this number of seconds so that the new definition agrees with the previous less accurate definitions. The agreed on definition is

The *meter* is the distance travelled by light in the vacuum in $\frac{1}{299\ 792\ 458}\ s$.

Definition of Mass

•*Mass* is not as obvious a physical quantity as length or time. The mass of a body is a measure of the amount of matter contained in it. At a given point on the earth, the mass of a body is proportional to *weight*, the force thatt the earth exerts on it.

•When someone says they have "lost weight" they really mean they have lost *mass*: they are made up of less matter than before. You could weigh less by just going to the moon, which would often be easier than losing mass.

Definition of a Kilogram

•The *SI* unit of mass is a *kilogram*. It is still defined as the mass of a piece of platinum kept at an Institute near Paris.

•A more useful definition (for atomic physics at least) is in terms of the mass of an atom. A Carbon atom (isotope C_{12}) has a mass of $19.926482 \times 10^{-27}\ kg$. That is a reasonable standard for atomic mass spectrometry. It is hard to relate this to every day masses, for which the traditional method of comparison with the standard kilogram is still the only way.

Big Distances

•Everything from the smallest to the largest is in the domain of physics. So we need a convenient way to deal with big and small numbers. *Powers of ten* are the usual way of denoting these big and small numbers. It is best to understand this in terms of some examples.

•A *kilometer* is $10^3 = 1000$ meters; The Earth has a radius of about $6 \times 10^6\ m$ or 6000 km. The distance from the Earth to the Sun is about $1.5 \times 10^8\ km$ or about 150 million kilometers. The distance to the next nearest star is 4×10^13 kilometers, to the next nearest galaxy $2 \times 10^{19}\ km$. The farthest object we have ever seen with a telescope is about $10^{23}\ km$ away; that is believed to be the about the size of the whole universe.

Big Numbers

•The prefixes *kilo* for 10^3, *mega* for 10^6, *giga* for 10^9, *tera* for 10^{12} have become widely accepted. The are additional ones such as *peta* for 10^{15}, which are in the books but are not widely used.

•In computerese, 1.2×10^3 is often written as 1.2e3,as 1.2E3, or as 1.2*10**3. This is really rather stupid since e has a quite a different meaning in mathematics. But we all have to suffer for the innumeracy of some computer programmers.

•To continue with examples, the mass of a typical person is about 100 kg; (That is 220 pounds.) The mass of a mountain is about $10^{12}\ kg$. The Sun has a mass of $2 \times 10^{30}\ kg$. A year is about $3.147 \times 10^7\ s$.

Small Numbers

•The prefixes *centi* for 10^{-2}, *milli* for 10^{-3},*micro* for 10^{-6}, *nano* for 10^{-9},*pico* for 10^{-12}, *femto* for 10^{-15} are standard. If you want to show off you can say *yocto* for 10^{-24} but only a couple of people in the textbook writing business will be impressed;-).

•The mass of a *speck of dust* is about a microgram. The shortest *pulse of light* ever produced has a duration of about a *femtosecond*.

•This lecture is 75 minutes too long; it must seem like 1.43 microcenturies.

Unit of Information

•The most basic piece of information is the answer to a question with just two possible answers: it is a *bit*;$2^3 = 8$ bits is a *byte*.

•In the world of computers, it is more convenient to think in terms of powers of two rather than ten, so we modify the meaning of the usual words for big numbers. $2^{10} = 1024$ bytes is a *kilobyte*, $2^{20} = 1.048576 \times 10^6$ bytes is a *megabyte*,$2^{30} \sim 1.073741 \times 10^9$ is a *gigabyte* and so on.