Physics concepts for Math 116

Here are, I think, all the physics concepts we will use in Math 116 this term. I won't do them justice, of course; you should take Physics 140 for that. This is just a vocabulary cheat-sheet.

I've included units for all the quantities, in both metric and English flavors. One of the best tricks the physicist has is to keep track of the units during a calculation. It's a great way to check that your answer makes sense, and it catches a lot of mistakes. It helps a lot to be familiar with the conversions, especially the metric-to-metric conversions, like $1\,\mathrm{N} = 1\,\mathrm{kg{\cdot}m/s^2}$.

There are, of course, many more units for each quantity. I've just given a couple. I recommend the site

`http://www.onlineconversion.com/`

if you want to convert units.

Time	
Metric units: seconds (s)	English units: seconds (s)
Conversions: None needed	

Time you know.

Length or Distance	
Metric units: meters (m)	English units: feet (ft)
Conversions: $1\,\mathrm{m} = 3.28\,\mathrm{ft}$, $1\,\mathrm{ft} = .305\,\mathrm{m}$, $1\,\mathrm{in} = 2.54\,\mathrm{cm}$	

Length you know. One inch is exactly 2.54 centimeters. They redefined the inch to make that true.

Area	
Metric units: square meters (m^2)	English units: square feet (ft^2)
Conversions: $1\,\mathrm{m}^2 = 10.8\,\mathrm{ft}^2$, $1\,\mathrm{ft}^2 = .0929\,\mathrm{m}^2$	

Area you know.

Volume	
Metric units: cubic meters (m^3), liter (ℓ)	English units: cubic feet (ft^3)
Conversions: $1\,\mathrm{m}^3 = 1000\,\ell$, $1\,\mathrm{m}^3 = 35.3\,\mathrm{ft}^3$, $1\,\mathrm{ft}^3 = .0283\,\mathrm{m}^3$	

Volume you know.

Velocity	
Metric units: meters per second (m/s)	English units: feet per second (ft/sec)
Conversions: $1\,\mathrm{m/s} = 3.28\,\mathrm{ft/s}$, $1\,\mathrm{ft/s} = .305\,\mathrm{m/s}$	

Velocity is how fast some length or distance is changing. It's signed; a positive value means the length is increasing, a negative value means it's decreasing.

Acceleration	
Metric units: meters per second per second ($\mathrm{m/s^2}$)	English units: feet per second per second ($\mathrm{ft/s^2}$)
Conversions: $1\,\mathrm{m/s^2} = 3.28\,\mathrm{ft/s^2}$, $1\,\mathrm{ft/s^2} = .305\,\mathrm{m/s^2}$	

Acceleration is how fast some velocity is changing. Positive if the velocity is increasing, negative if it's decreasing. If an object falls near the Earth, it accelerates at a constant rate due to gravity. We call this acceleration g, and it's equal to $9.8\,\mathrm{m}/s^2$ or $32\,\mathrm{ft/s^2}$.

Mass	
Metric units: kilograms (kg)	English units: —
Conversions: None	

Mass is how much of a substance you have. On earth, our weight is proportional to our mass, and we blur the distinction between the two. People in Europe will say, "I weigh 70 kilograms," which is not technically correct; see below for what weight is. The important distinction is that your mass would stay the same if you left Earth, but your weight would change. For instance, on the moon, you would weigh about $\frac{1}{6}$ of what you weigh on earth.

The English system does have a unit for mass. It's called the slug (really!) It's very rarely used. You've probably never heard of it unless you've taken a physics class. When using English units, we will talk in terms of weight, rather than mass.

Mass Density	
Metric units: kilograms per cubic meter ($\mathrm{kg/m^3}$), kilograms per liter (kg/ℓ)	English units: —
Conversions: $1000\ \mathrm{kg/m^3} = 1\ \mathrm{kg}/\ell$	

Mass density is the ratio of mass to volume of a given substance. For instance, gold has a density of 19.3 grams per cubic centimeter, which is $19{,}300\,\mathrm{kg/m^3}$. So one gold bar of size

$$7\,\mathrm{in} \times 3.625\,\mathrm{in} \times 1.75\,\mathrm{in} = 44.4\,\mathrm{in}^3 = 7.28 \times 10^{-4}\,\mathrm{m}^3,$$

such as the ones stored in Fort Knox, has mass

$$(7.28 \times 10^{-4}\,\mathrm{m}^3) \times 19300\,\mathrm{kg/m^3} = 14.0\,\mathrm{kg}.$$

Plain water has the very nice density of $1\,\mathrm{kg}/\ell = 1000\,\mathrm{kg/m^3}$. In fact that's how the metric units were picked, to make that number come out nice.

Note: the problems in our book actually call a variety of things "density". When they're talking about a rod, for instance, they might talk about "linear density", meaning how much mass there is per meter of rod, at a particular point. Or it might be population density along a road. So the word "density" has many uses. When unqualified, it ususlly means mass density, but you should read any problem carefully to figure out what it means by "density".

Force	
Metric units: Newtons ($\mathrm{N} = \mathrm{kg\,m/s^2}$)	English units: Pounds (lb)
Conversions: $1\,\mathrm{N} = .225\,\mathrm{lb}$, $1\,\mathrm{lb} = 4.45\,\mathrm{N}$	

Force is how hard you push or pull something. Newton's second law of motion says that

$$\textsc{Force} = \textsc{Mass} \times \textsc{Acceleration}$$

or $F = ma$. In other words, if you apply a force F to an object of mass m, then (in the absence of any other forces) it will accelerate at a rate F/m. Since objects near the Earth's surface accelerate at a rate g, you can conclude that the force the Earth is exerting on an object of mass m is mg. We call this force the object's *weight*. For instance, a 1 kg object weighs

$$1\,\mathrm{kg} \times 9.8\,\mathrm{m/s^2} = 9.8\,\mathrm{N} \approx 2.20\,\mathrm{lb}.$$

So the gold bar above weighs $14.0 \times 2.20 = 30.9\,\mathrm{lb}$.

Weight Density	
Metric units: —	English units: Pounds per cubic foot ($\mathrm{lb/ft^3}$)
Conversions: Weight density = Mass density $\times\, g$	

Since we use weight with English units, rather than mass, we use "weight density" instead of mass density. It's just what you think: the ratio between the weight and the volume of a substance. We can figure out the weight density of gold from what we know about the bar: its volume is

$$44.4\,\mathrm{in}^3 \times \left(\frac{1\,\mathrm{ft}}{12\,\mathrm{in}}\right)^3 = .0257\,\mathrm{ft}^3$$

so the weight density of gold is

$$\frac{30.9\,\mathrm{lb}}{.0257\,\mathrm{ft}^3} \approx 1200\,\mathrm{lb/ft^3}.$$

The weight density of water is $62.4\,\mathrm{lb/ft^3}$. So a cubic foot of water weighs 62.4 pounds. That number always seemed high to me; after all, a gallon of water only weighs a little over 8 pounds. So apparently it's possible to put between 7 and 8 gallons into one cubic foot. Who knew?

Work	
Metric units: Joules or Newton-meters (j = N·m)	English units: foot-pounds (ft·lb)
Conversions: $1\,\mathrm{j} = .738\,\mathrm{ft{\cdot}lb}$, $1\,\mathrm{ft{\cdot}lb} = 1.36\,\mathrm{j}$	

When you push an object and it moves, you do work. The amount of work is

$$\textsc{Work} = \textsc{Force applied} \times \textsc{Distance moved}.$$

For instance, suppose you lift the gold bar to a height of 2 meters off the ground. The force you needed to apply was exactly the weight of the bar; if you apply less, you can't pick it up, and if you apply more, it will accelerate away from you like a shotput. That would be bad, so don't do that. The work it takes to lift the bar is therefore

$$\begin{aligned}\text{distance raised} \times \text{weight of bar} &= 2\,\mathrm{m} \times (\text{mass of bar} \times g) \\ &= 2\,\mathrm{m} \times 14\,\mathrm{kg} \times 9.8\,\mathrm{m/s}^2 \\ &= 274\,\mathrm{N{\cdot}m}.\end{aligned}$$

Well, so what? Why do we give a special name to this force times distance thing? The answer is that work is the same thing as energy, and energy is the most important concept in physics, period. That's because energy is *conserved*, meaning you can convert it from one form to another, but you can't create it or destroy it. (Barring a nuclear reaction, but that's another story.) So it takes 274 joules to raise the bar, and then you've stored that energy in the bar, as "potential energy". If you drop the bar, you'll get the energy back, as "kinetic energy" (the energy of motion). When the bar hits the floor, it will convert that kinetic energy into heat and sound. Furthermore, earlier you had to eat some food which you converted into the energy to lift the bar.

The point is, energy is moved around, but can't be manufactured or destroyed. So that's why work is important.