CSUC Spring Term 2020
Physics 204A sections 6, 7, 8

Lecture 1. for Week 9, March 23 – 29

*This lecture presumes that you have read **chapter 9** in your text. Remember, when we say "read" … we mean read-read-read. Reading Physics is going to ruin your literature reading speed. Sorry!*

In this chapter we introduce the idea of energy. In fact, we introduce the idea of "conserved quantities" altogether! Ultimately, we will examine three such quantities: Energy, Momentum, and Angular Momentum. Most people are more familiar with energy than the other two – though as we shall find out, this is already deep intellectual territory we are in. Whatever energy "is" … it's subtle. In fact, it was the last of the three to be "put in stone" – and that happened only very late (think ≈ 1900 because only then were idea about thermal energy being really solidified). Like so many another "Great Idea" energy will *transcend* the place it came from! Later, when we study Quantum Mechanics and Relativity etc. energy will absolutely take center stage … and those studies are ***way*** beyond Newton. So the idea of energy is found inside of "Newtonian Physics" but is certainly not confined to it. Not by a long shot.

Key Things to Focus on and Remember:

• The universal connecting idea through this discussion is and will always be "WORK". Work has a definition and an understanding. Both can be confusing. The definition is simple enough … only it's not! Yeah, and the understanding is hugely subtle too, so … O.K. … let's have at it!

THE DEFINITION: We say that a quantity of work dW has been done by a force $\vec{\boldsymbol{F}}$ when the force is applied to an object … and that object "displaces" by $d\vec{\boldsymbol{r}}$. We simply define the work performed as: $dW \equiv \vec{\boldsymbol{F}} \cdot d\vec{\boldsymbol{r}}$.

THE CONFUSION: **a)** direction counts! $\vec{\boldsymbol{F}} \cdot d\vec{\boldsymbol{r}} = F_x dx + F_y dy + F_z dz$ … you **must** use a dot product. We could logically talk about $\hat{x}\ work$, $\hat{y}\ work$ and $\hat{z}\ work$ having been done. **b)** we get to talk about work done by "individual forces" whereas we are aware that only "Net Force" appears in Newton's 2nd Law. **c)** we only get to *define* work for infinitesimal steps since the magnitude and direction of the force and displacement may be changing step by step. **d)** "net-work" will then be computed by "adding up" work performed over all the steps.

THE UNDERSTANDING: We need to internalize that work is to be viewed as a "TRANSFER OF ENERGY". The transfer is taking place from the "force source" to the "object that displaces".

THE CONFUSION: Energy isn't a "thing". You can't "hold it" or "see it" or "smell it" …none-the-less …you **can** "account for it". In that respect … it acts **"as if"** it were a "thing". That's the magic of Physics! It's an over-all "aspect", "quality", "characteristic", "feature" … (you choose your own word) associate with any physical situation – that can be accounted for, and that means it's a measurable quantity.

It is a highly "ABSTRACT" idea. We will have many expressions for the amount of energy to be found in different circumstances … and all of these expressions come from the Work-Energy Theorem.

• In Newtonian Mechanics … ***everything*** we can say about energy must come from Newton's Laws. This will happen through the "WORK-ENERGY THEOREM". Consequently, anything you can say about energy is NOT as much information as is contained in Newton's Laws.

THE WORK-ENERGY THEOREM:

a) Start from Newton's second law.
b) Follow a **"real-mass"** along its **"real-trajectory"** in **"real-time" … its "path through space"**.
c) Pick any two points along that trajectory. Call them the "initial-point" and the "final-point".
d) It follows mathematically that:

$$\left(\frac{1}{2}m\,v^2\right)_{final} - \left(\frac{1}{2}m\,v^2\right)_{initial} = Net\ Work\ done\ on\ mass\ along\ path$$

…or …

$$\left(\frac{1}{2}m\,v^2\right)_{final} - \left(\frac{1}{2}m\,v^2\right)_{initial} = \int_{initial\ position}^{final\ position} \vec{F}\cdot d\vec{r}$$

Where the integral is to be evaluated along the actual physical trajectory.

This is just a mathematical consequence of Newton's second law … yeah, but we are going to interpret it as having **enormous** "Physical Meaning". In fact … all statements about energy will come from here! In the simple cases in the current problem set associated with this chapter …we will actually be able to evaluate the right hand side explicitly. This will give us powerful knowledge about how things are changing (or NOT !) as the dynamics of the problem unfold.

A simple but non-trivial example illustrates the situation: "BALLISTICS" . This is where gravity is the only force in the picture. Now, if we take gravity as pointing along the $-z$ axis (where the x-y plane is reserved for "horizontal"), then the force on our mass point is: $\vec{F}_{grav} = -mg\hat{z}$. From here it follows that $\vec{\boldsymbol{F}}\cdot d\vec{\boldsymbol{r}} = -mg\ dz$. So now we get to conclude that for ***any*** ballistic trajectory … taking *any two points* along it … that:

$$\left(\frac{1}{2}m\,v^2\right)_{final} - \left(\frac{1}{2}m\,v^2\right)_{initial} = \int_{initial\ position}^{final\ position} -mgdz \;\; = -mg(z_f - z_i)$$

Wow …! Consider shooting a cannon ball off the castle walls. Let's take the initial spot at the point of departure and final spot when it hits the ground. Well then … the speed it hits the ground with apparently doesn't depend on the angle you shoot it! It's nowhere in this relationship. It depends only on the speed it started with and the height of the wall it left from! This surprising result is an *energy truth*. No one saw it coming. So what else is in there to be found out? A whole lot I can assure you!