Chapter 3

Energy

Introduction

- **Physics**: The study of **Motion, Matter, and Energy**.
  - **Motion** produces energy (windmills, dams, etc.).
  - **Matter** produces energy (fuels, batteries, etc.).
- **Energy** is a central, unifying concept in Physics.
  - Most of the rest of the course will be about Energy, so what is it?
  - That's difficult to answer quickly, because Energy has many forms.
- It helps to first discuss the concept of **Work**.
  - The scientific definition is of work **very restricted** compared to your everyday use of the term.

Work

- **Work** is a measure of the effort (or the energy) involved when a **Force** moves an object through a **Parallel Displacement (d)**.

• **Work Def.:** $\boxed{W = Fd \quad (F \text{ and } d \textbf{ must} \text{ be parallel})}$

  - Work is a SCALAR. UNITS later.
- **Work Done ON Object** moved is what we calculate in Physics.
  - Work is also done BY objects.
- If the force is not parallel to the displacement, only the **parallel** part is used to calculate the **Work Done.** (3 Figs., Ed.5.)
  - **When Lifting**: (Ed.5, Fig. 4.2 again)
    - Any Horizontal portions of motion require no work ON object.
    - ∴ Work Done = Vertical distance (height) x weight.
  - **When Pushing Horizontally**: (Ed.5, Fig. 4.5)
    - Only the horizontal component of force contributes to work done.

Units of Work

- **SI:** joule [J], 1 J = 1 N·m = 1 kg·m^2/s^2.
- **English:** ft·lb (no special name)
  - **DON'T USE** "lb·ft", it's a unit for "Torque", a twisting force.
  - The English units for work **and power** are

    NOT used in the problem sets, lab, and tests in this course.

Power

- **Power** is rate at which work is being done.
  Power is Work done divided by the Time taken to do it.

- **Power Def.:** $$\boxed{P = \frac{W}{t}}$$
  - **SI Units:** watt [W], 1 W = 1 J/s
    - **NOTE**: Avoid confusion among these 3 symbols when hand written: *W* work, W watt, ***w*** weight. ·
  - **English Units:** ft·lb/sec.
  - **Special Metric & English Unit:** horsepower [**hp**], 1 hp = **746 W** = 550 ft·lb/sec
    - To do problems our problems where power is in hp, **first convert to the metric "standard" unit [J]**.

- **Do Ex. B-16, p.90, (using Metric units instead of English).**
  - In this course, use only the METRIC Power units **hp** and **J**.

Motion, Position, and Energy

- **Energy** is a fundamental and somewhat abstract concept.
  It's difficult to picture mentally.

••• Energy is: the ability to do Work, (OR stored Work).

- When work is done **ON** an object, its **Energy INCREASES**.
- When work is done **BY** an object, its **Energy DECREASES**.

- Energy and Work have the same units: joules [J] (OR ft·lb).
- There are 5 different **FORMS** that energy can take:
  - mechanical • chemical • radiant • electrical • nuclear.
  - **Mechanical energy** is the **energy of Molecules**,
    acting either **together** as an object or **individually**.
    It can be further broken into 5 **TYPES**:
    - **Gravitational Potential & Kinetic** - acting **together** (this Chapter).
    - **Heat, Sound, Elastic Potential** - acting **individually** (later).

(Gravitational) Potential Energy (PE)

- (Grav.) **Potential Energy** is energy of vertical position (**height**).
  - If an object is lifted, the work done on it increases its **PE**.
  - If an object is allowed to drop, its stored **PE** decreases and it COULD do work on something else (pulley on **p.73**).

•• PE Definition: $\boxed{PE = (mg)h = wh}$

- **NOTE**: The **PE** value depends on the reference level chosen for **h=0**. (Usually the lowest level in the problem is chosen if there is no other stated level.)
- **Choice is NOT important**, because:
  - Only **changes** in **PE** enter into actually using PE.
  - Thus only **height differences** are important.

Kinetic Energy (KE)

- **Kinetic Energy** is energy of motion (**speed**).

•• **KE Definition:** $\boxed{\mathbf{KE} = \frac{1}{2}\mathbf{mv}^2 \left(= \frac{\mathbf{mv}^2}{2} \right)}$

- To **INcrease KE**:
  1. Do work $(F \cdot d)$ on object to increase its speed.
  2. (Other ways are described later.)
- To **DEcrease KE**:
  1. Let object slow by doing work on something else (bowling on **p.74**).
  2. Apply **Force** in **Opposite** direction to decrease object's speed.
     (Physically, this is doing work that has a negative sign.)

• **Do Ex. B-13, p.90.**

Energy Flow

Work and Energy

- If work is done on an object, it **MUST** be moved a **distance** by a **force**.
  - Needing a force means that something **opposed** the motion.
    - We classify work as **done AGAINST** whatever opposes motion.
      (In most real situations, we have combinations of opposition.)
  - Also, the work done changes some form of the object's energy.

Work Done AGAINST	Energy That Changes	Formula	Work Storage Reversible?
Inertia	Kinetic	$\mathbf{W_{in} = KE_f - KE_i}$	100%
Fundamental Forces	Potential	$\mathbf{W_{in} = PE_f - PE_i}$	100%
Shape	Potential	$\mathbf{W_{in} = PE_f - PE_i}$	100%
Frictional Forces	Heat (**Internal Kinetic**)	Next Chapter	Less Than 100%

- Work against Friction is **not** 100% recoverable.

Energy Conversion and Transfer

- Energy may be **Converted** from one **Form or Type** to another.
  - **EXPERIMENTS show:**
    total energy **After** the conversion **ALWAYS** = total energy **Before**.
- For Example: (for object dropped from rest with no air resistance),

  Energies are PE & KE: $\mathbf{Total Energy = E = PE + KE}$

- Since total energy is constant, the final energy = the initial energy:

  E after & before: $\mathbf{PE_f + KE_f = PE_i + KE_i}$

  Rearrange Terms: $\mathbf{KE_f - KE_i = PE_i - PE_f}$

  ReLabel Difference: $\mathbf{KE_{gained} = PE_{lost}}$

- For an object dropped from rest from a height, ***h***:

  Substitute Definitions: $\mathbf{\frac{1}{2}mv_f^{\,2} = mgh}$

  Solving for Velocity: $\mathbf{v_f = \sqrt{2gh}}$

- **Do** **Ex. B-17-b, p.90.** **(using Metric units instead of English)**

Energy Form Conversion Chain

- **Chemical**: (Conversion chain USUALLY starts here.)
  - Burning Fuel (86% of all Energy Production); and other reactions.
- **Nuclear**: (Number two Production method, stuck at 8%)
  - Nuclear Reactions convert Mass into Energy. $\left(\mathbf{E = mc^2}\right)\left(\approx 10^{17}\ \mathbf{J/kg}\right)$
- **Electrical**:
  - Easiest to change into the other forms. (More later.)
- **Radiant**:
  - Light, infra-red, microwaves, radio & TV waves, etc. (More later.)
- **Mechanical Potential**:
- **Mechanical Kinetic**:
  - **Sound**:
    - Vibrating **Objects**, a SPECIAL type of **KE**. (More later.)
  - **Heat**: **ALL ENERGY ENDS UP AS HEAT !!!**
    - KE on a molecular scale, (**Next chapter**).

Energy Conservation

- Repeated **OBSERVATIONS** show:
  - **If there is no WORK into or out of a set of objects, their TOTAL ENERGY remains constant**.
    (Conversions from one energy form to another often occur.)
  - There is no theory to prove this, but it has **always** been true.
  - Imagine the entire universe is the set of objects:
    - Work in or out requires an outside interaction.
    - There is nothing outside.
    - Thus there can be no work into or out of the universe.
  - **TOTAL ENERGY of the UNIVERSE is constant**.

• DEMO Read Feynman.

$$\left(\begin{array}{c}\text{Total}\\ \text{Blocks}\end{array}\right)=\left(\begin{array}{c}\text{Blocks}\\ \text{Seen}\end{array}\right)=28$$

$$\left(\begin{array}{c}\text{Total}\\ \text{Blocks}\end{array}\right)=\left(\begin{array}{c}\text{Blocks}\\ \text{Seen}\end{array}\right)+\left(\begin{array}{c}\text{Blocks}\\ \text{Lost}\end{array}\right)=28$$

$$\left(\begin{array}{c}\text{Total}\\ \text{Blocks}\end{array}\right)=\left(\begin{array}{c}\text{Blocks}\\ \text{Seen}\end{array}\right)+\left(\begin{array}{c}\text{Blocks}\\ \text{Lost}\end{array}\right)-\left(\begin{array}{c}\text{Blocks}\\ \text{Added}\end{array}\right)=28$$

$$\left(\begin{array}{c}\text{Total}\\ \text{Blocks}\end{array}\right)=\left(\begin{array}{c}\text{Blocks}\\ \text{Seen}\end{array}\right)+\left(\begin{array}{c}\text{Blocks}\\ \text{Lost}\end{array}\right)-\left(\begin{array}{c}\text{Blocks}\\ \text{Added}\end{array}\right)+\frac{\text{Box Wt.}-16\,\text{oz.}}{3\,\text{oz.}}=28$$

$$\left(\begin{array}{c}\text{Total}\\ \text{Blocks}\end{array}\right)=\left(\begin{array}{c}\text{Blocks}\\ \text{Seen}\end{array}\right)+\left(\begin{array}{c}\text{Blocks}\\ \text{Lost}\end{array}\right)-\left(\begin{array}{c}\text{Blocks}\\ \text{Added}\end{array}\right)+\frac{\text{Box Wt.}-16\,\text{oz.}}{3\,\text{oz.}}+\frac{\text{Water Ht.}-6\,\text{in.}}{\frac{1}{4}\,\text{in.}}=28$$

Energy Sources Today

The Sun

- Original Source of **all our energy** (**EXCEPT FOR NUCLEAR**).

Petroleum and Natural Gas

- Decayed plant and animal matter.
- Known supplies used up this century.

Coal

- Decayed plant matter formed under special conditions.
- Coal contains **sulfur** as an impurity.
  - Burns to sulfur dioxide —> Falls as **acid rain**.
- Known supplies used up this century.

Water (& Wind) Power

- Water falls, converts its **PE** into **KE**, turns Electric Generators.
- Limited number of places with high water.
- Efficient Windmill Electric Generators are new technology.

Nuclear Power

- **Fission**: (Splitting Atoms)
  - Nearly unlimited supply.
  - Waste is a problem. (Radioactive)
- **Fusion**: (Fusing Hydrogen into Helium) Sun: is a **Fusion Reactor**.
  - Practically unlimited supply of Hydrogen.
  - No waste disposal problem (**Helium gas**).
  - Still a long way from learning how to control it.

Energy Sources Tomorrow

- Our hope for the future to sharply reduce Petroleum and Coal requirements.
- The currently most useful sources are:

Solar Technologies

- **Solar Cell**: **In very wide use today in order to**:
  Supply power to Calculators and automatically control Light Bulbs.
  An Electronic device that generates electricity directly from light.
  The technology is explained more fully on **p.180** in the Electricity Chapter.
- **Active Applications**: Move heat into buildings from outside collectors.
- **Wind Energy**: Windmills are an old technology that is being re-explored.
- **Passive Applications**: Design buildings for good use of the sun.

Geothermal Energy

- A few buildings have been designed this way for heating, but cost is high.