Lec #8: Mechanical Energy. II.

LAST TIME: Mechanical Energy. I.
- Wrap-Up Discussion: Lessons of History
- Forms of Energy; Conversion of Energy
- Newton's Laws of Motions; Forces

TODAY: Mechanical Energy. II.
- Work, Power, and Energy
- Kinetic Energy, Potential Energy

NEXT WEEK: Thermal Energy. I. (read Chapter 4)

Forces in Nature

- Gravity $F = G\, m_1 m_2/r^2$
  - $g = G\, M_e/R_e^2 = 9.8\ m/s^2 = 32\ ft/s^2$
  - on Earth, F = mg
- Electric $F = q_1 q_2/r^2$
  - attractive or repulsive
- *Magnetic* (electromagnetic)
- Nuclear
- These are all "conservative".
  - depend only on position
  - mechanical energy is conserved (with proper accounting)

- Unfortunately (?), mother nature has other forces that are not conservative
  - mechanical energy NOT conserved
  - depend on something other than position
- examples
  - Friction: depends on "roughness" of surface, velocity, mass
  - Drag: depends on aerodynamics (shape); cube of velocity!

Vectors v. Scalers; Units

Position	**s**(t) (x,y,z v. time)	meters (m) feet (ft)
Velocity	**v**(t) = d**s**/dt speed = | **v**(t) |	meters/second (m/s) feet/second (ft/s) (fps)
Acceleration	**a**(t) = d**v**/dt = d^2**s**/dt^2	(m/s)/s = m/s^2 ft/s^2
Mass	measure of inertia amount of "stuff"	kilograms (kg) slugs
Force	**F**; long-range forces contact forces	Newtons (kg m / s^2) pounds (lb)

Rotational Analogs

Displacement	$\theta(t)$	dimensionless: radians 2π rad = 360^o
Angular Velocity	$\omega(t) = d\theta/dt$	radians/sec (s^{-1})
Angular Acceleration	$\alpha(t) = d\omega/dt$ $= d^2\theta/dt^2$	(s^{-2})
Moment of Inertia	$\mathbf{I} = \int m(r)\, dr$	(kg m)
Torque	$\tau = I\, \alpha$	(Nt m)

WORK

Work = Force x Distance

- really, it's Work = $\mathbf{F} \cdot \mathbf{s} = F\, s \cos\theta$!
- only net force in direction of motion is relevant
- scalar, not vector
- (+) if force is applied in direction of motion, work is done TO the "system"; "energy" is added to the system; system accelerates; velocity increases
- (-) if force is applied in opposite direction, energy is removed FROM system; system decelerates; velocity decreases

- If all forces are "conservative" (and if you allow for "*potential energy*"):

  Work = Δ (Mechanical Energy)

  (change in mechanical energy)

- Energy is measure of "Capacity to do Work"

- In the REAL world, there is never a perfect conversion between work and "*kinetic energy*"
  – Friction, drag, etc. non-conservative
  – Where does energy go?
  – ΔEnergy = Work + ? (next week)

Power

- Rate at which work is done. Energy / time
  – defined "instantaneously"; depends on how fast you move something with a force
  – Power is what we transfer from our electrical outlets to our appliances (e.g. to turn a motor) or from our engine to turn our wheels
  – Energy is what we pay for (but maybe we would be better off if they could meter power)
- Units: energy/time
  – Joule/second (1 Watt = 1 J/s)
  – Horsepower (1 HP = 746 W)

Kinetic Energy

- energy associated with motion
- could be converted to work if motion brought to a halt

$$KE = (1/2)\ m\ v^2$$

  – scalar, not vector (v is speed, not **v**elocity)
  – SI units: kg $m^2\ s^{-2}$ = Nt m = Joule (J)
  – cgs units: g $cm^2\ s^{-2}$ = erg (1 erg = 10^{-7} J)
  – english units: slug $ft^2\ s^{-2}$ = foot-pound
  – other units: calorie, BTU, kilowatt-hour

Kinetic Energies for Various Objects

Object	mass (kg)	speed (m/s)	KE (J)
Earth orbiting Sun	6.0 E -24	3.0 E 4	2.7 E 33
Moon orbiting Earth	7.4 E -22	1.0 E 3	3.8 E 28
Rocket @ escape speed	500	1.1 E 4	3.1 E 10
Car @ 55 mph	2000	25	6.3 E 5
Running athlete	70	10	3.5 E 3
rock dropped from 10m	1	14	9.8
golf ball @ terminal speed	.046	44	4.5
raindrop @ terminal speed	3.5 E -5	9	1.4 E -3
oxygen molecule in air	5.3 E -26	500	6.6 E -21

~10^{20} J used in US annually

Potential Energy

- if force is conservative, change in POSITION can be converted to a change in VELOCITY (i.e. just let go and let force act over a distance)
- Total Mechanical Energy = constant

  = Mechanical KE + Mechanical PE

- e.g. Gravity
  – PE=work=force x distance= (mg)(h)
  – hold above ground: v=0, KE=0, PE=mgh
  – drop; hits ground w/ v=gt, KE=$1/2mv^2$, PE=0

Summary of Units

Table 2.4 UNITS IN MECHANICS

Quantity	SI	English	Conversions
Velocity	m/s	ft/s	1 ft/s = 0.305 m/s 1 mph = 0.447 m/s
Acceleration	m/s^2	ft/s^2	1 ft/s^2 = 0.305 m/s^2
Force	newton (N)	lb	1 lb = 4.45 N
Energy	joule (J)	ft-lb	1 ft-lb = 1.356 J
Power	watt (W)	ft-lb/sec, hp	550 ft-lb/s = 1 hp = 746 W

E = P x t, so 1 kWh = 1000 J/s * 3600 s

kWh is a unit of energy; what is electricity cost/kWh?

Examples of Mechanical Energy

- *direct* use of energy to produce motion
  - automobiles, trains, airplanes, etc.
  - motors & generators
  - pumps and compressors
  - fans
  - labor saving appliances and tools
  - others?
- what else do we use energy for?

Lab 1: Mechanical Energy

- Everyone record their own measurements (but you can help each other out). Make sure you have all the data you need to work the lab.
- Write-Up Due next Monday (nothing formal, just show your work and discuss what you learned.