Lec #6: Energy Fundamentals

LAST TIME: Expiring Resources and Crises

TODAY: Mechanical Energy (Chapters 2 & 3)

- Forms of Energy
- Laws of Motion; Forces in Nature
- Work, Kinetic Energy, Potential Energy, Power
- Conservation of Energy

NEXT: Thermal Energy; Thermodynamics (Chapters 4 &5)

Newton's Laws of Motion

- 1st Law of Motion: *any object will continue in its present state of motion (speed and direction) unless/until it is "acted upon" by a net outside "force"*
  - object at rest ---> stays at rest
  - object in motion ---> stays in motion at a constant speed and in a straight line
  - this seems to contradict every day experience, and maybe even "common sense"
  - our world is full of frictional forces, but they are not present in the "vacuum" of space

"INERTIA"

- 2nd Law of Motion: *to change an object's state of motion, a net "force" must be applied*; *amount of change is directly proportional to amount of force*

  Force = mass x acceleration
  - acceleration can be change in speed **or** direction
  - mass is a measure of inertia (resistance to change)
  - Ponder this for now: What is a "Force?"
  - this simple equation forms the basis of the Physics of motion; it led to the development of Calculus
- 3rd Law of Motion: *for every force applied to an object, there is an equal force in the opposite direction from that object*

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, $F = mg$
- Electrostatic $F = q_1 q_2/r^2$
  - 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 so that
  - 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)

- **s, v, a, F** are vector quantities
- related with *differentiation* and *integration*
- Newton invented calculus for just this reason

- e.g. Motion due to gravity @ Earth's surface
  $\mathbf{F} = m\mathbf{a} = m\mathbf{g}$ (g = constant = 9.8 m/s^2 toward Earth)
  $\mathbf{a} = \mathbf{g} = d\mathbf{v}/dt = d\mathbf{s}^2/dt^2$
  $\mathbf{v} = \int_0^t \mathbf{g}\, dt = gt + v(t=0)$
  $\mathbf{s} = \int_0^t \mathbf{v}\, dt = 1/2\, gt^2 + s(t=0)$

- e.g. a=0
  v = constant; $(s-s_0) = v\, t$ [distance=rate x time]

Rotational Analogs

Displacement	$\theta(t)$	dimensionless: radians 2π rad = 360°
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)

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?

- example: forces acting on an automobile

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 Chapter)

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

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)

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 <u>energy</u>; what is electricity cost/kWh?

Recap

- KE = (1/2) m v^2
  - change in speed -> change in KE
  - note: can change **v**elocity w/out change in KE
- Work = Force x Distance x (cos θ)
- So PE = Force x Distance (e.g. mgh for gravity)
- If forces are "conservative":
  - Mechanical KE + Mechanical PE = constant
  - Work = change in Mechanical Energy
- If *not* conservative, where does the energy go?