Physics Lecture 3 – Equilibrium, Torque and Energy

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Equilibrium

$$\sum F_x = 0, \quad \sum F_y = 0, \quad \sum F_{up} = \sum F_{down}, \quad \sum F_{right} = \sum F_{left}$$

- Static equilibrium: all velocities are zero
- Dynamic equilibrium: velocities are constant, but not zero
- Objects not in equilibrium will have a net force and therefore acceleration: $F_{net} = ma$

Torque

$$\tau = F \times r = Fr \sin\theta$$

- Force making an object want to rotate
- Can be either clockwise or counterclockwise
- At rotational equilibrium, $\tau_{clockwise} = \tau_{counterclockwise}$
- You can choose the point of rotation arbitrarily, but usually choose the point where it'll naturally rotate

Energy

- Units: $\text{joule (J)} = 1\ \text{kg}\frac{\text{m}^2}{\text{s}^2}$, $\text{electron volt (eV)} = 1.6 \cdot 10^{-19}\ J$
- Mechanical energy: sum of kinetic and potential energy
- Kinetic energy: energy of motion $= K = \frac{1}{2}mv^2$
- Potential energy: energy stored in position
  - *Gravitational PE*: energy due to gravity $U_g = mgh$
  - *Elastic PE*: energy due to object deformation (*e.g.* springs) $= U_e = \frac{1}{2}k\Delta x^2$
- For kinematics problems, you have a conversion between potential and kinetic energy but their sum is constant
- Isolated system: no energy or mass exchange with surroundings
- Closed system: energy is exchanged but mass is not
- Conservation of energy: when you have an isolated system, total energy is constant; when you have a closed system, energy can only leave as work or heat

Work

- Work done by non-frictional force: $W = F \cdot d = Fd\cos\theta$
  - Using only component of F in the direction of movement: $W = Fd$
  - Also equal to the change in total energy: $W = \Delta K + \Delta U$
  - *Example*: lifting an object to a height h changes only U by $+mgh$, so you're doing $W = mgh$ on the object
- Work done by friction will also cause a change in internal energy
  - Still equal to the change in total energy: $W = \Delta K + \Delta U + \Delta E_i$

Power

$$P = \frac{W}{t}$$

- Rate of energy transfer, or rate at which work is being done
- Instantaneous power:

$$P = \frac{W}{t} = \frac{Fd\cos\theta}{t} = F\left(\frac{d}{t}\right)\cos\theta = Fv\cos\theta = Fv \text{ if } F \text{ in the same direction as } v$$