Newton’s Law of Universal Gravitation

- Every particle in Universe attracts every other particle with force:
  - directly proportional to product of masses
  - inversely proportional to square of distance between them.

\[ F = G \frac{m_1 m_2}{r^2} \]

inverse square law

\( G = \) universal gravitational constant
\( = 6.673 \times 10^{-11} \text{ N m}^2/\text{kg}^2 \)

Acceleration due to gravity \( g \) will vary with altitude

\[ F = G \frac{M_E m}{r^2} \quad \Rightarrow \quad g = G \frac{M_E}{r^2} \]

- \( r \) is the distance from Earth’s center
- \( g \) is not constant

Gravitational Potential Energy

- \( PE = mg y \) is valid only near the earth’s surface
- For objects high above the earth’s surface, an alternate expression is needed

\[ PE = -G \frac{M_E m}{r} \]

- Zero reference level is infinitely far from the earth

Escape Speed

- speed needed for an object “escape” from planet

\[ v_{\text{esc}} = \sqrt{\frac{2GM_E}{R_E}} \]

- For the earth, \( v_{\text{esc}} \) is about 11.2 km/s
- Note, \( v \) is independent of the mass of the object

Torque and Equilibrium

- First Condition of Equilibrium
  - The net external force must be zero

\[ \sum \vec{F} = 0 \quad \text{or} \quad \sum F_x = 0 \quad \text{and} \quad \sum F_y = 0 \]

- This is a statement of translational equilibrium
- The Second Condition of Equilibrium states

\[ \sum \vec{t} = 0 \]

- The net external torque must be zero

Three Factors affect torque

- The magnitude of the force
- The position of the application of the force
- The angle at which the force is applied

\[ \tau = rF \sin \theta \]
Center of Gravity

- In finding the torque produced by the force of gravity, all of the weight of the object can be considered to be concentrated at a single point.

\[ x_{cg} = \frac{\sum m_i x_i}{\sum m_i} \quad \text{and} \quad y_{cg} = \frac{\sum m_i y_i}{\sum m_i} \]