Physic² 121:
Phundament°ls of Phy²ics I

November 13, 2006

Newton's Law of Universal Gravitation

- Every particle in the Universe attracts every other particle with a force that is directly proportional to the product of the masses and inversely proportional to the square of the distance between them.

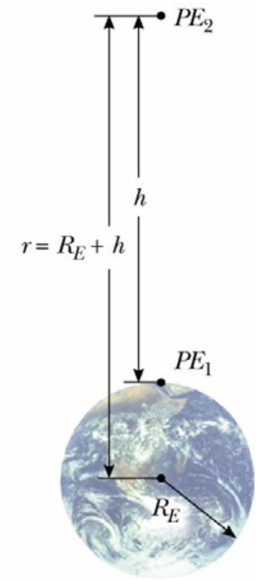
$$F = G\frac{m_1 m_2}{r^2}$$

Gravitational Potential Energy

- PE = mgy 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
  - Otherwise, PE < 0 (negative)



Escape Speed

- The escape speed is the speed needed for an object to soar off into space and not return
- Initial Energy:

$$E_i = KE + PE$$
$$= \tfrac{1}{2}mv^2 - G\frac{M_E m}{R_E}$$

- Really far from the earth ($r \to \infty$), PE $\to$ 0. To "escape", object needs to get infinitely far away. To just barely escape, it will slow down to zero at $r = \infty$, so KE = 0. This means total energy = 0:

$$0 = \tfrac{1}{2}mv^2 - G\frac{M_E m}{R_E}$$
$$\tfrac{1}{2}mv^2 = G\frac{M_E m}{R_E}$$
$$v_{esc} = \sqrt{\frac{2GM_E}{R_E}}$$

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

Kepler's Laws

- All planets move in elliptical orbits with the Sun at one of the focal points.
- A line drawn from the Sun to any planet sweeps out equal areas in equal time intervals.
- The square of the orbital period of any planet is proportional to cube of the average distance from the Sun to the planet.
  - $T^2 \propto r^3$

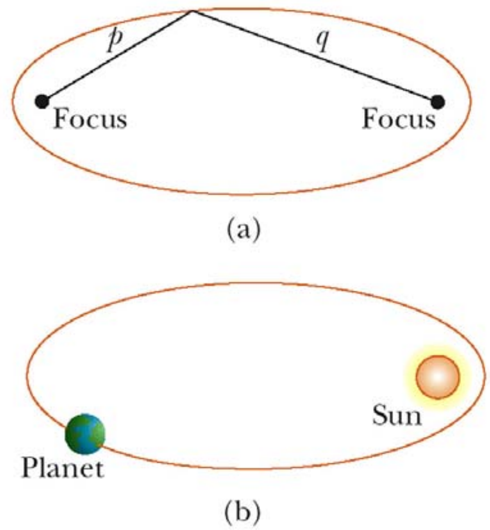
Kepler's Laws, cont.

- Based on observations made by Tycho Brahe

- Newton later demonstrated that these laws were consequences of the gravitational force between any two objects together with Newton's laws of motion

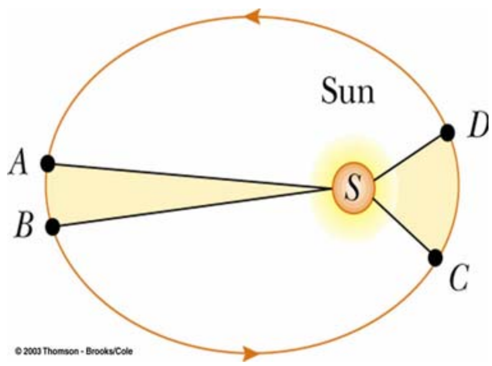
Kepler's First Law

- All planets move in elliptical orbits with the Sun at one focus.
  - Any object bound to another by an inverse square law will move in an elliptical path
  - Second focus is empty



Kepler's Second Law

- A line drawn from the Sun to any planet will sweep out equal areas in equal times
  - Area from A to B and C to D are the same



Kepler's Third Law

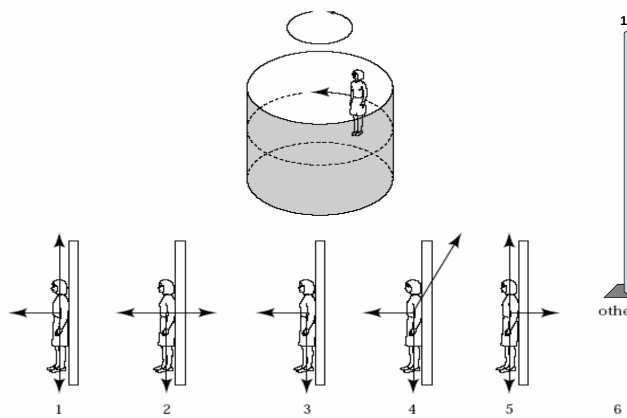
- The square of the orbital period of any planet is proportional to cube of the average distance from the Sun to the planet.

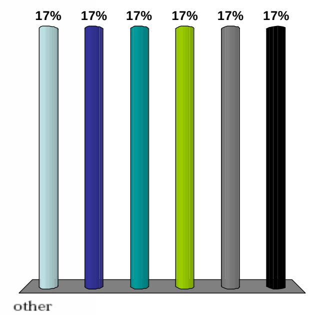
$$T^2 = Kr^3$$

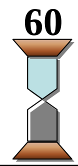
  - For orbit around the Sun, $K = K_S = 2.97\text{x}10^{-19}\ s^2/m^3$
  - K is independent of the mass of the planet

? A rider in a “barrel of fun” finds herself stuck with her back to the wall. Which diagram correctly shows the forces acting on her?

1.
2.
3.
4.
5.
6.







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1	2	3	4	5															

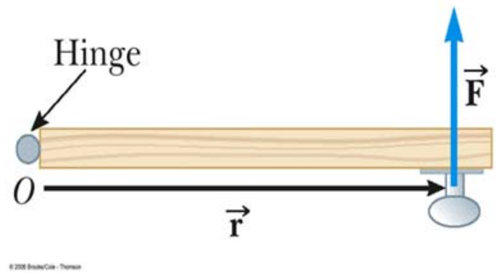
Chapter 8

Rotational Equilibrium
and
Rotational Dynamics

Force vs. Torque

- Forces cause accelerations
- Torques cause angular accelerations
- Force and torque are related

Torque



- The door is free to rotate about an axis through O
- There are three factors that determine the effectiveness of the force in opening the door:
  - The *magnitude* of the force
  - The *position* of the application of the force
  - The *angle* at which the force is applied

Torque, cont

- Torque, τ, is the tendency of a force to rotate an object about some axis
  - $\tau = r F$
    - τ is the torque
      - symbol is the Greek tau
    - F is the force
    - r is the length of the position vector
- SI unit is N·m

Direction of Torque

- Torque is a vector quantity
  - The direction is perpendicular to the plane determined by the position vector and the force
  - If the turning tendency of the force is counterclockwise, the torque will be positive
  - If the turning tendency is clockwise, the torque will be negative

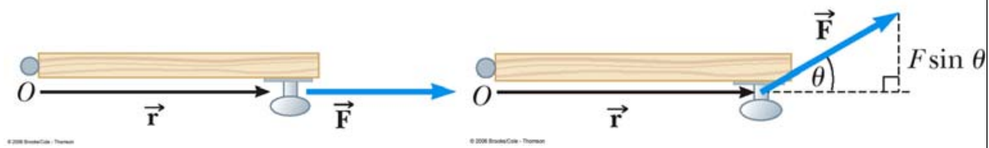
Multiple Torques

- When two or more torques are acting on an object, the torques are added
  - As vectors
- If the net torque is zero, the object's rate of rotation doesn't change

General Definition of Torque

- The applied force is not always perpendicular to the position vector
- The component of the force *perpendicular* to the object will cause it to rotate

General Definition of Torque, cont

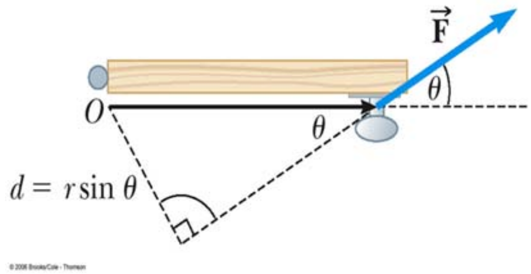


- When the force is parallel to the position vector, no rotation occurs
- When the force is at some angle, the perpendicular component causes the rotation

General Definition of Torque, final

- Taking the angle into account leads to a more general definition of torque:
  - $\tau = r F \sin\theta$
    - F is the force
    - r is the position vector
    - θ is the angle between the force and the position vector

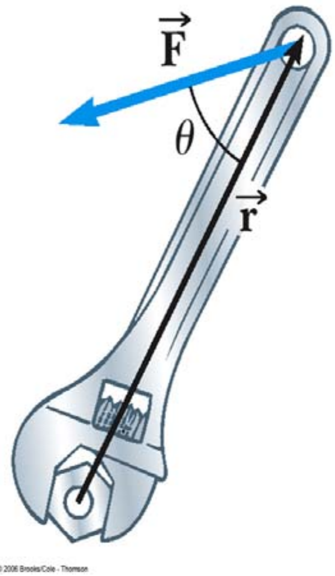
Lever Arm



- The *lever arm*, d, is the perpendicular distance from the axis of rotation to a line drawn along the direction of the force
- d = r sin θ

Right Hand Rule

- Point the fingers in the direction of the position vector
- Curl the fingers toward the force vector
- The thumb points in the the direction of the torque



Net Torque

- The net torque is the sum of all the torques produced by all the forces
  - Remember to account for the direction of the tendency for rotation
    - Counterclockwise torques are positive
    - Clockwise torques are negative

Torque and Equilibrium

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

$$\Sigma \vec{\mathbf{F}} = 0 \ or$$

$$\Sigma \vec{\mathbf{F}}_x = 0 \ \ and \ \ \Sigma \vec{\mathbf{F}}_y = 0$$

  - This is a necessary, but not sufficient, condition to ensure that an object is in complete mechanical equilibrium
  - This is a statement of translational equilibrium

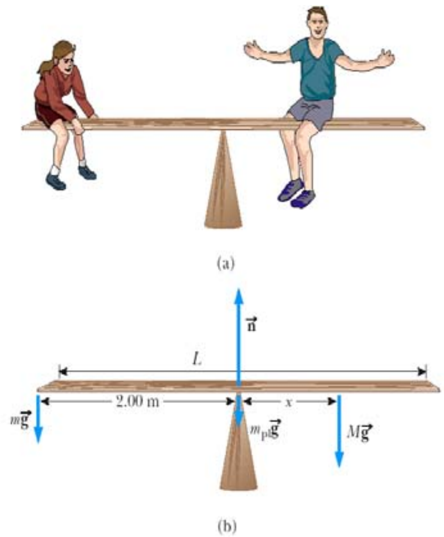
Torque and Equilibrium, cont

- To ensure mechanical equilibrium, you need to ensure rotational equilibrium as well as translational
- The Second Condition of Equilibrium states
  - The net external torque must be zero

$$\Sigma \vec{\tau} = 0$$

Equilibrium Example

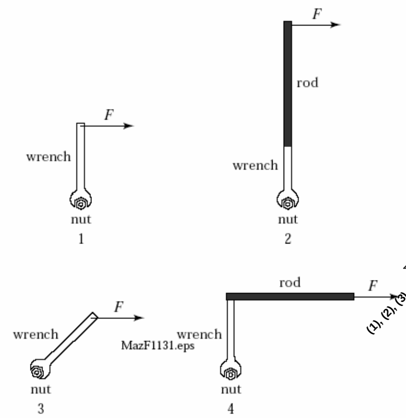
- The woman, mass m, sits on the left end of the see-saw
- The man, mass M, sits where the see-saw will be balanced
- Apply the Second Condition of Equilibrium and solve for the unknown distance, x

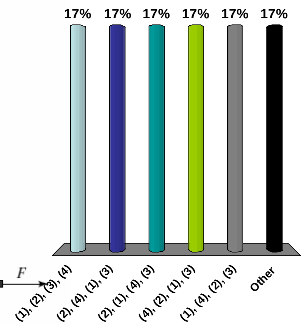


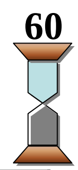
?

You are using a wrench and trying to loosen a rusty nut. Which of the arrangements shown is most effective for loosening the nut? List in order of descending efficiency.

1. (1), (2), (3), (4)
2. (2), (4), (1), (3)
3. (2), (1), (4), (3)
4. (4), (2), (1), (3)
5. (1), (4), (2), (3)
6. Other







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