CSD2301 Lecture
4. Newton's Laws of Motion

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Outline

- Newton's Laws of Motion
  - Concept of Force
  - First Law
  - Second Law
  - Third Law
- Problem-solving Strategy

Newton’s Laws of Motion

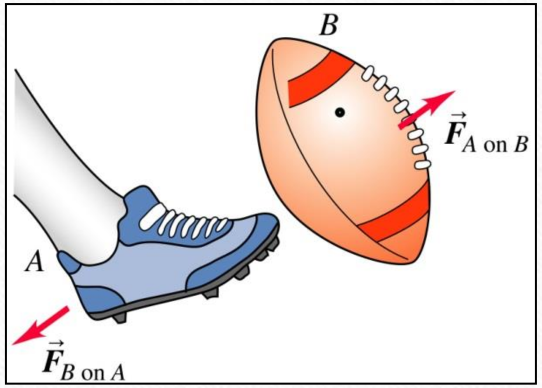
- Formulated by English physicist and mathematician Sir Isaac Newton
- 3 laws of motion
- Relationship between the **forces** acting on a body and the **motion** of the body
- Foundation of classical mechanics
  - Study of how objects react when forces act upon them

Concept of Force

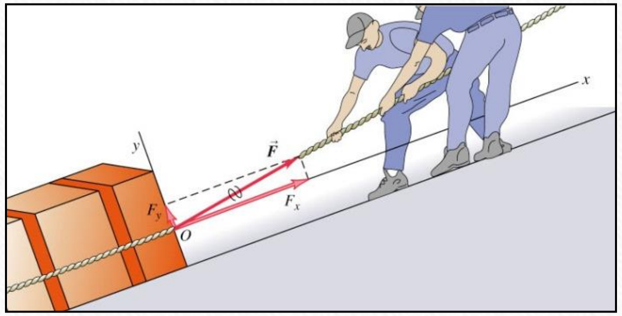
- Force represents the interaction of an object with its environment.
- When an object is at rest or uniform velocity, it said to be in **equilibrium**.
- A net non-zero force on an object causes it to accelerate.
- 2 kinds of forces:
  - **Contact forces** represent the result of physical contact between two objects (e.g. pulling, compressing a spring) This is present only during the "contact". Does not remain in the body when the "contact" is over.
  - **Field forces** do not involve physical contact between two objects but act through empty space (e.g. electrical, gravitational forces)

Concept of Force

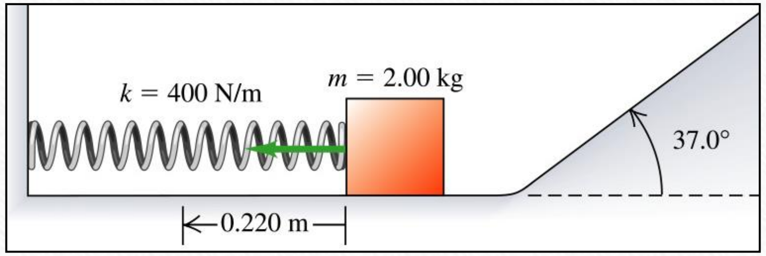
- Examples of forces:



Forces when kicking a ball



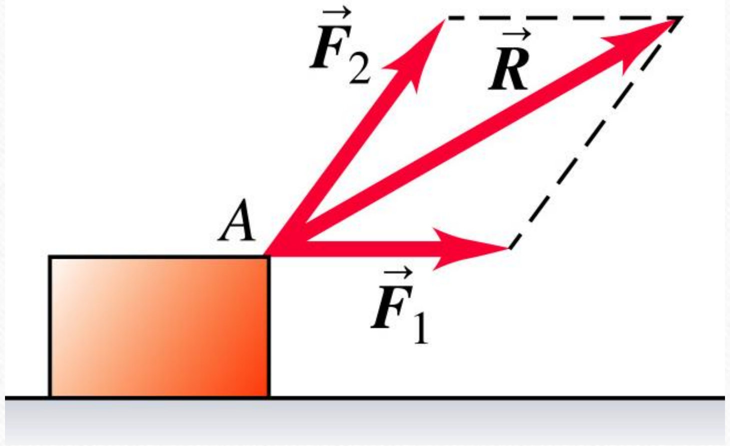
Forces while dragging a block upslope



Spring force

Concept of Force

- Force is a vector
  - Has magnitude and direction
- Resultant of forces acting on object:



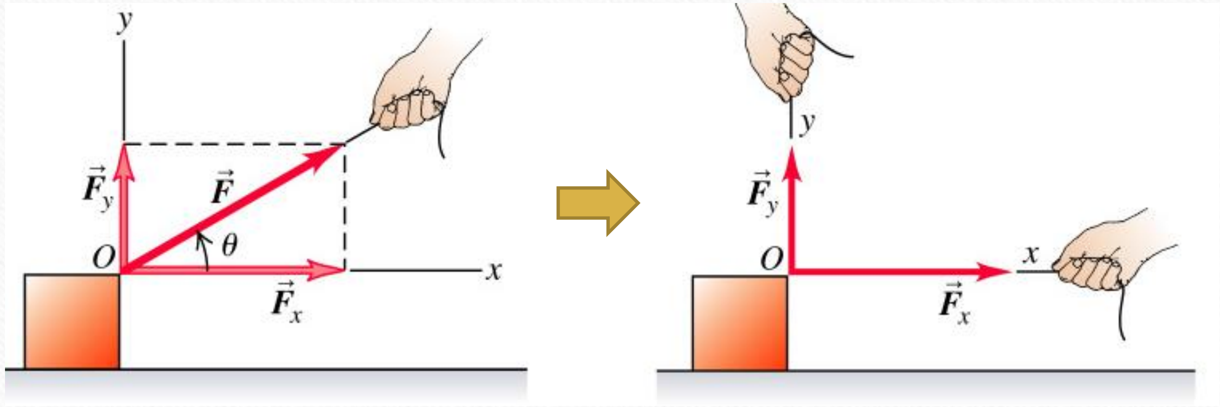
$$\boxed{\vec{R} = \vec{F}_1 + \vec{F}_2}$$

Concept of Force

- In general, for more than 2 forces acting:

$$\vec{R} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots = \sum \vec{F} \quad \left(= \sum_i \vec{F}_i \right)$$

- Can resolve into perpendicular components:

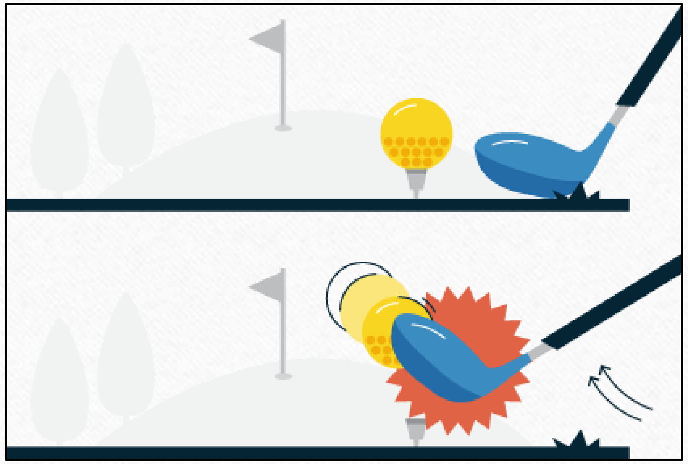


Newton's First Law

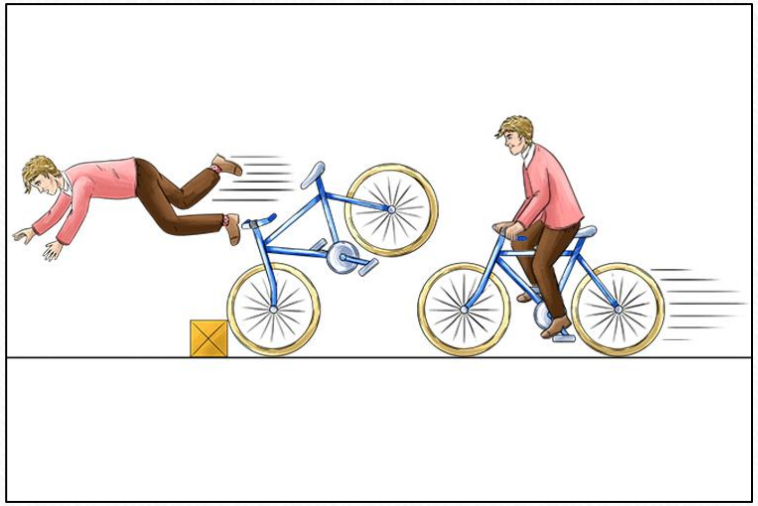
- States that: If a body is at rest or moving at a constant speed in a straight line, it will remain at rest or keep moving in a straight line at constant speed unless it is acted upon by a force.
    - Concept of **Inertia:** The tendency of an object to resist any attempt to change its velocity
        - For e.g. bowling ball is more resistant to changes in its velocity than a basketball, we say it has **greater inertia** than the basketball.

Newton’s First Law

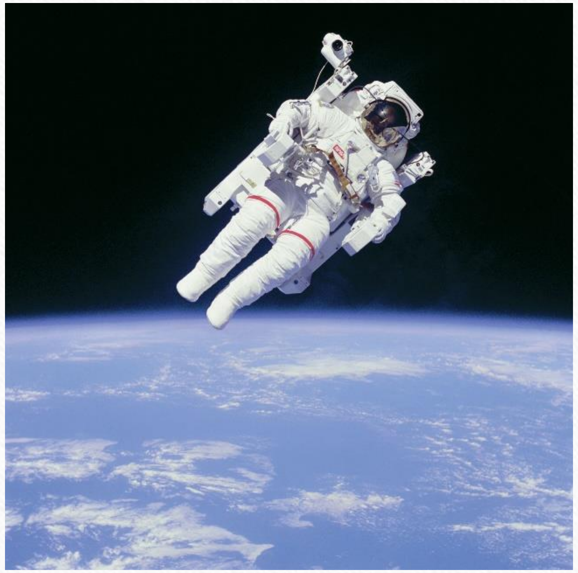
- Some examples:



Golf ball starts moving

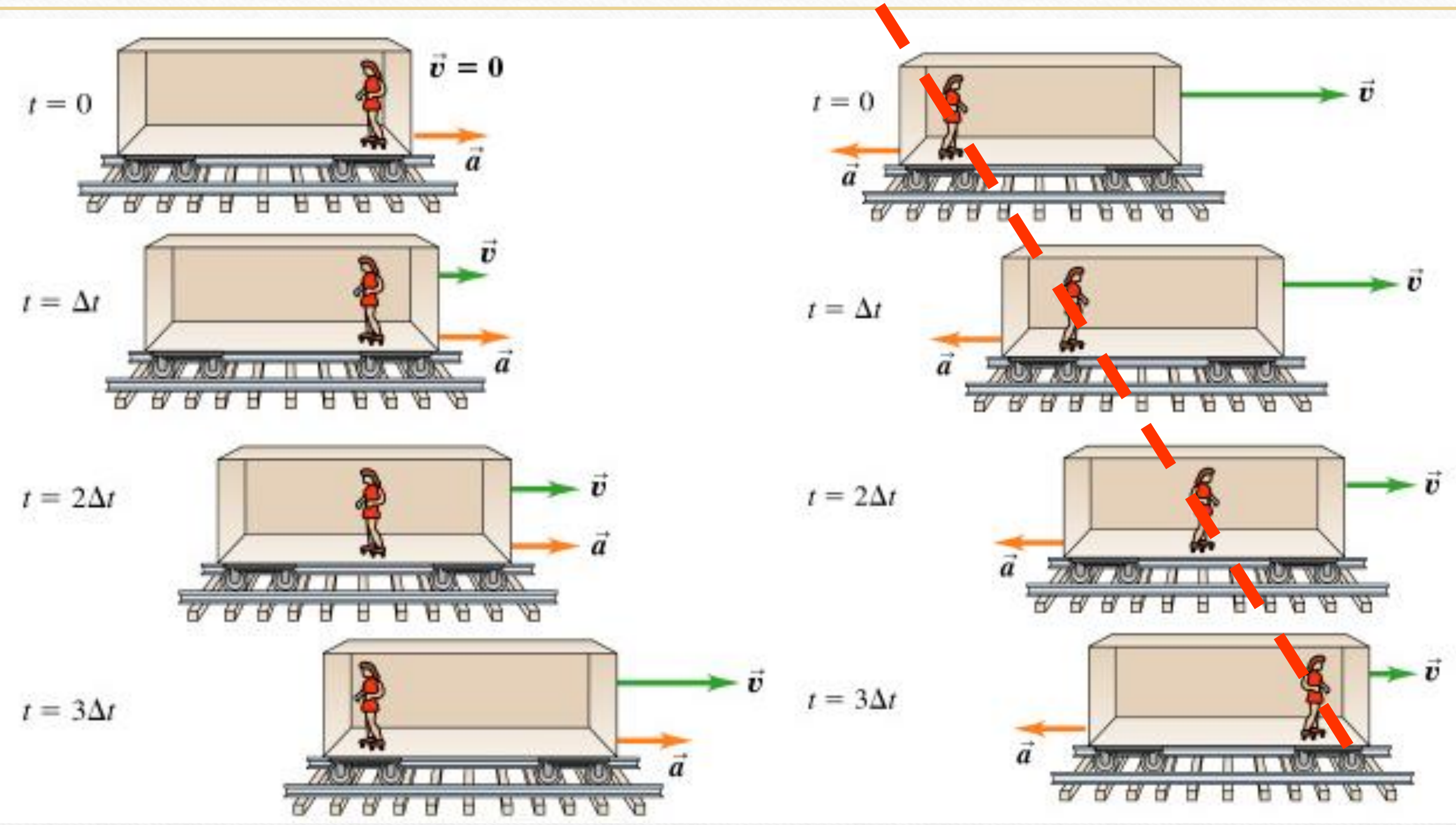


Cyclist continues in motion



Astronaut continues in motion

Newton's First Law

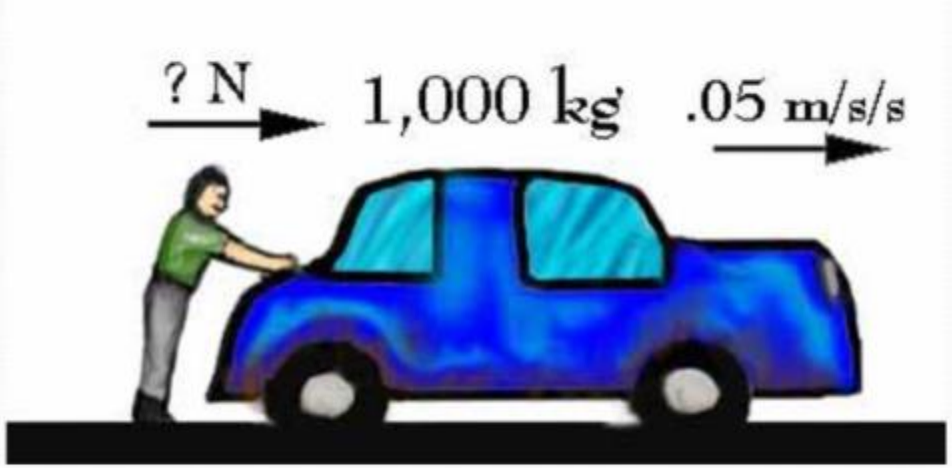


Newton's Second Law

- States that: Time rate of change of the momentum of a body is equal in both magnitude and direction to the force imposed on it
- Quantitative description of the changes that a force can produce on the motion of a body
- For a body whose mass m is constant, it can be written in the form **$F = ma$**, where F is force and a is acceleration. Units: $kg.m/s^2 = N$ (newton)
  - If a body has a net force acting on it, it is accelerated. Conversely, if a body is not accelerated, there is no net force acting on it.

Newton's Second Law

- Example:



F= 1,000 x 0.05

Answer = 50 N

Newton's Second Law

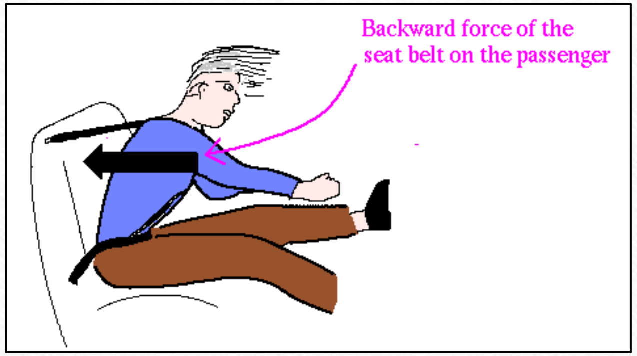
- **Weight** is a force.
- The force exerted by the Earth on an object is called the weight of the object
  - $F = ma = mg$ $(=W)$
- Weight is a vector acting downwards (on Earth)
- Weight depends on geographical location
  - It is not an inherent property of a body (unlike mass)
  - Weight can change or even be 0, but mass always remains the same

Newton's Third Law

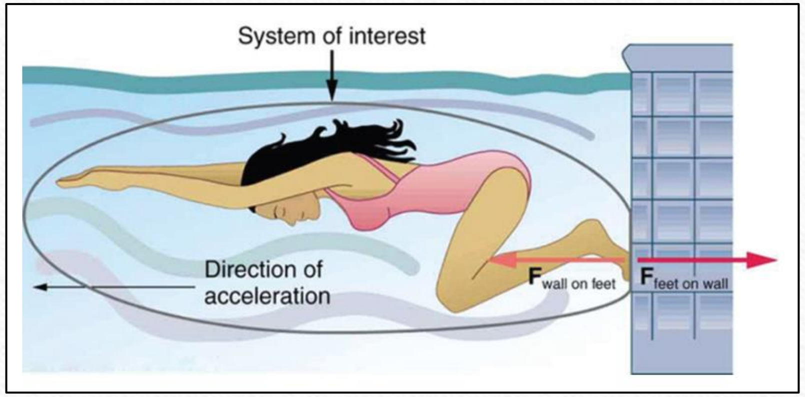
- States that: when two bodies interact, they apply forces to one another that are equal in magnitude and opposite in direction
  - aka. Law of action and reaction
- Concept is used to analyse problems of **static equilibrium**
- Described forces (such as reaction force) are real forces

Newton's Third Law

- Examples:



Seat belt exerts reaction force when car brakes



Wall exerts force on swimmer

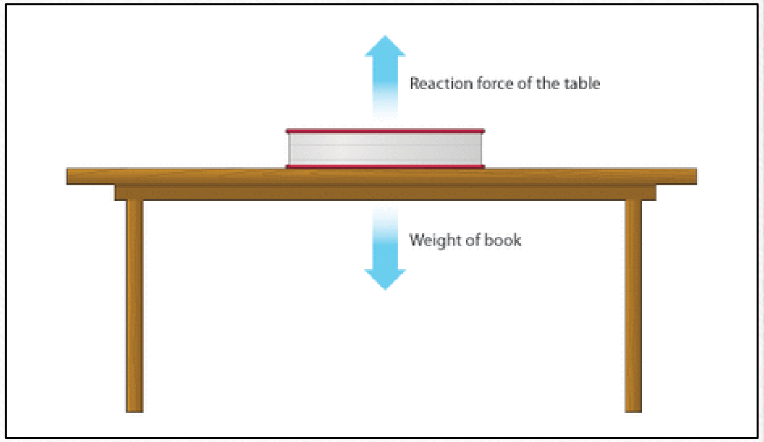
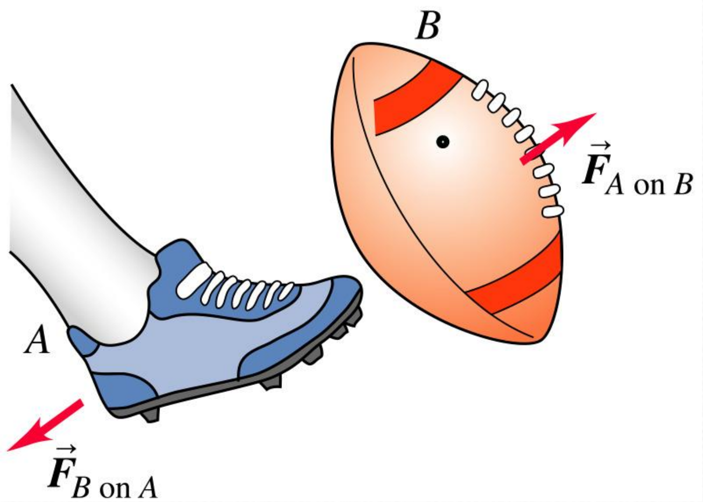


Table exerts reaction force on the book

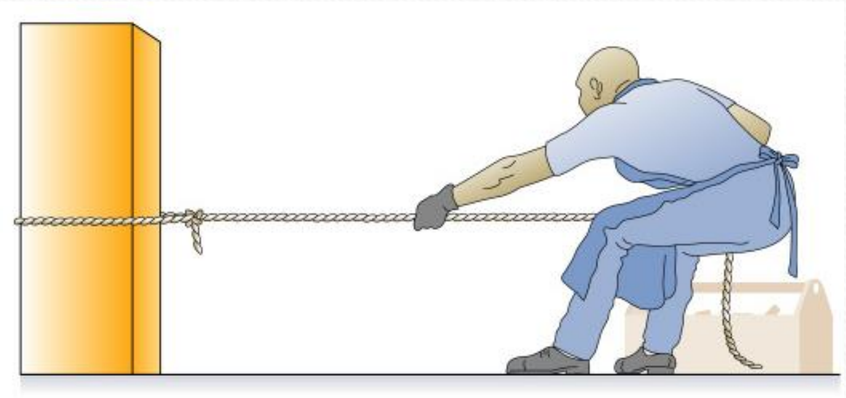
Newton's Third Law

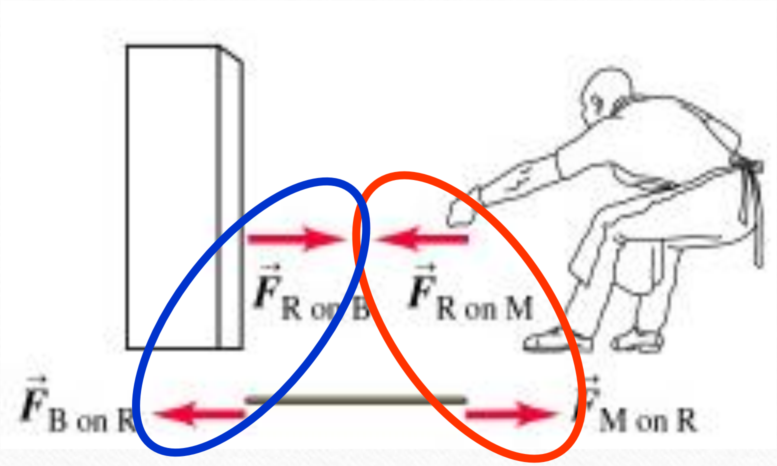
- Example: the force $F_{A\text{ on }B}$ exerted by object *A* on object *B* is **equal in magnitude to and opposite in direction** to the force $F_{B\text{ on }A}$ exerted by object *B* on object *A*.



Newton’s Third Law

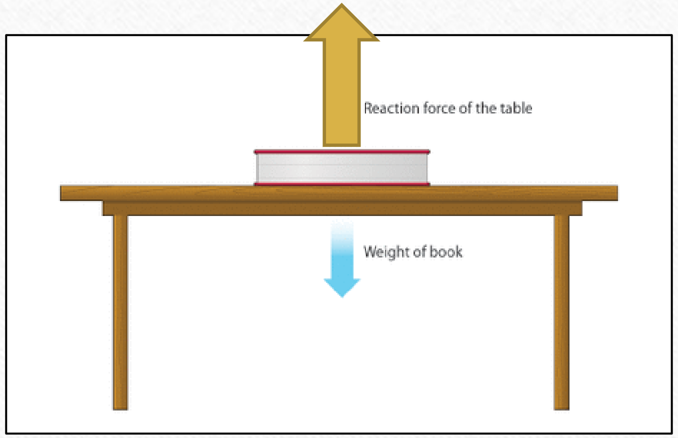
- Example:
  - Illustrating a man pulling a block with a rope
  - 2 sets of action-reaction pair as circled





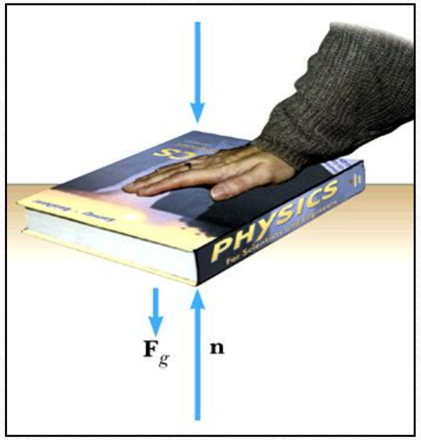
Normal (contact) Force

- A type of reaction force
- For objects on Earth resting on a surface (e.g. object on table), the **normal force** balances the force of gravity and provides equilibrium
- When these forces are perpendicular to the ground, they are also called a **normal force**.



Normal (contact) Force

- The magnitude of the normal force is **not necessarily equal to** magnitude of gravitational force.
- When one object pushes downward on another object with a force F, the normal force n **is greater than** the force of gravity.



$$\boxed{n = F_g + F}$$

Problem-solving Strategy

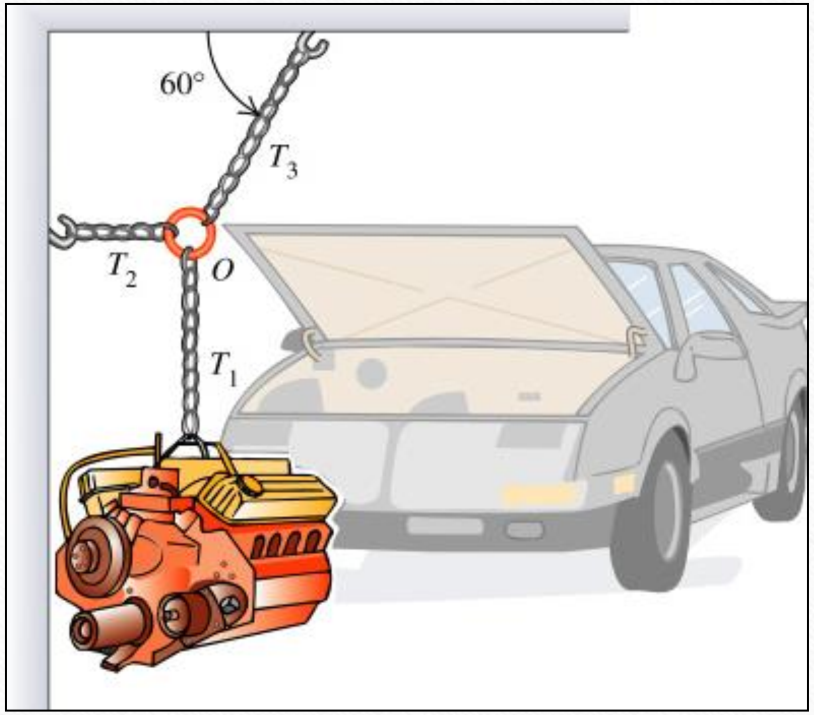
1. Draw a neat, simple diagram of the system.
2. Isolate each body being analysed; draw a **free-body diagram** showing all external forces.
3. Establish **convenient axes** for each body and **find the component forces** along these axes; apply Newton's first or second law in component form.
4. Solve the component equations; ensure you have **as many independent equations as you have unknowns**.

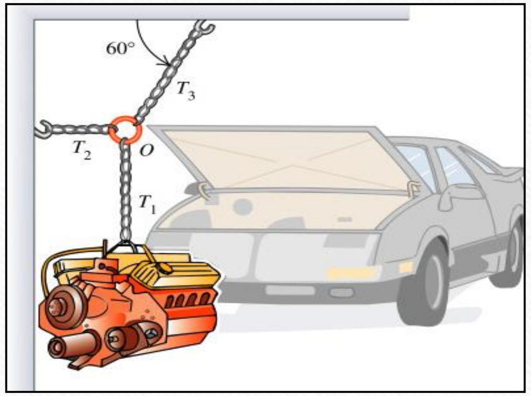
Problem-solving Strategy

- Assumptions:
  - Objects are point masses (neglect rotation)
  - Neglect effects of friction (unless specified)
  - Neglect mass of ropes involved (unless specified)
- When Newton's Laws are applied, focus only on **external forces** that act on each body

Example: Car Engine in Equilibrium

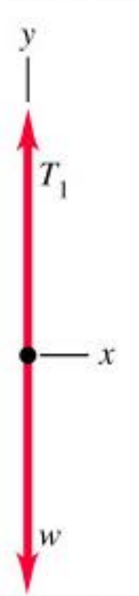
- A car engine with weight w hangs from a chain that is linked at ring O to two other chains, one fastened to the ceiling and the other to the wall. **Find the tensions in each of the three chains.** Assume that <u>w is known</u> and the weights of the ring and chains are negligible.



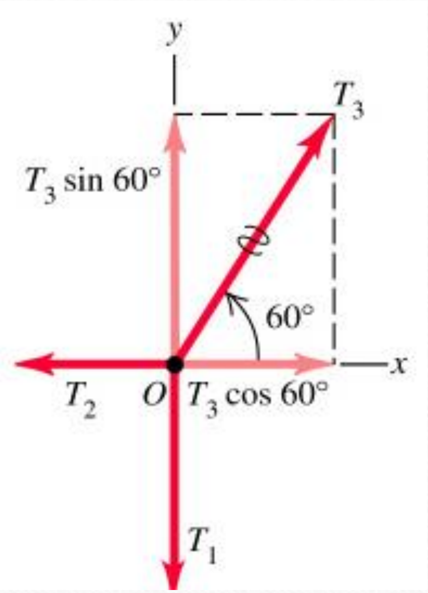


- Find the tensions in each of the three chains.
- w is known

1. Isolate engine



2. Isolate O ring



3. Summation of forces

$$\sum F_y = T_1 + (-w) = 0 \longrightarrow T_1 = w$$

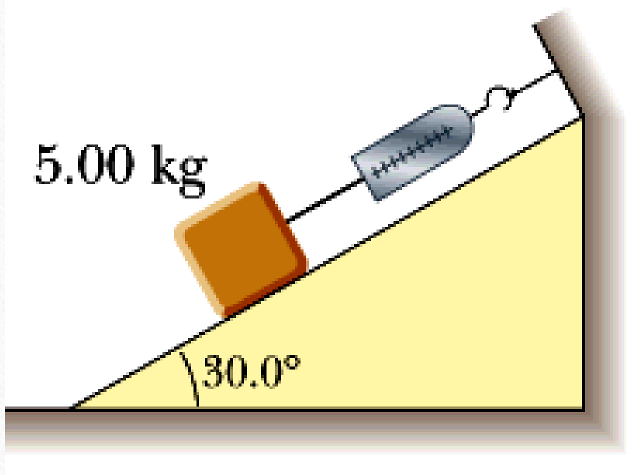
$$\sum F_y = T_3 \sin 60^\circ + (-T_1) = 0 \longrightarrow T_3 = \frac{T_1}{\sin 60^\circ} = 1.155w$$

$$\sum F_x = T_3 \cos 60^\circ + (-T_2) = 0 \longrightarrow T_2 = w\frac{\cos 60^\circ}{\sin 60^\circ} = 0.577w$$

Problem solved!

Example: Tension

- What is the reading of the spring balance? Neglect masses of spring and string. Assume frictionless surface.



Example: Tension

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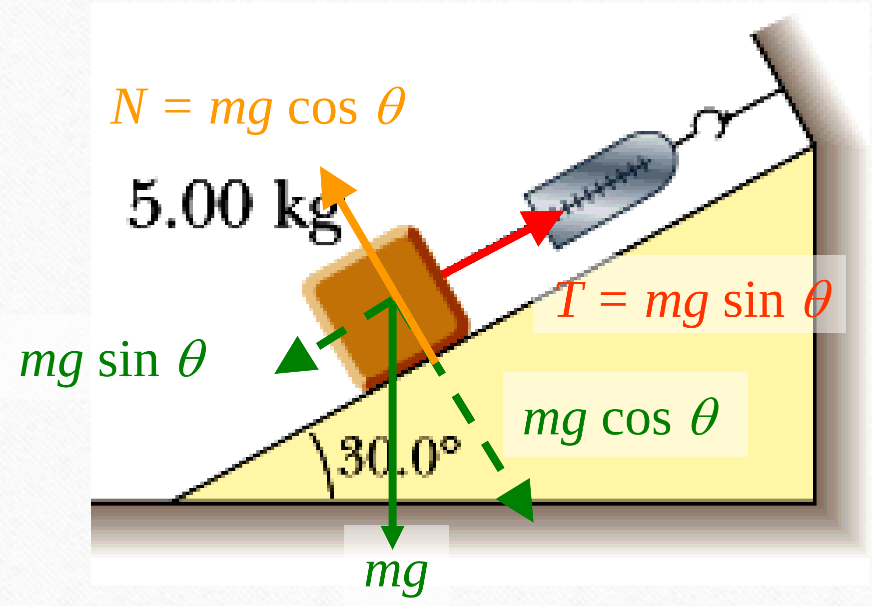
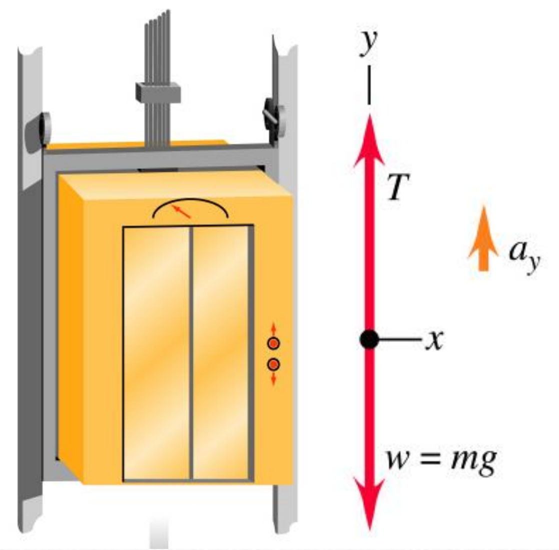


Reading = T = mg sin θ = 5(9.8) sin 30° = 24.5 N

Example: Tension in Elevator Cable

An elevator and its load have a total mass of 800 kg. The elevator is originally moving downward at 10.0 m/s; it slows to a stop with constant acceleration in a distance of 25 m. Find the tension *T* in the supporting cable while the elevator is being brought to rest.



$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

$$a_y = \frac{0^2 - (-10)^2}{2(-25)} = +2.00 \text{ m/s}^2$$

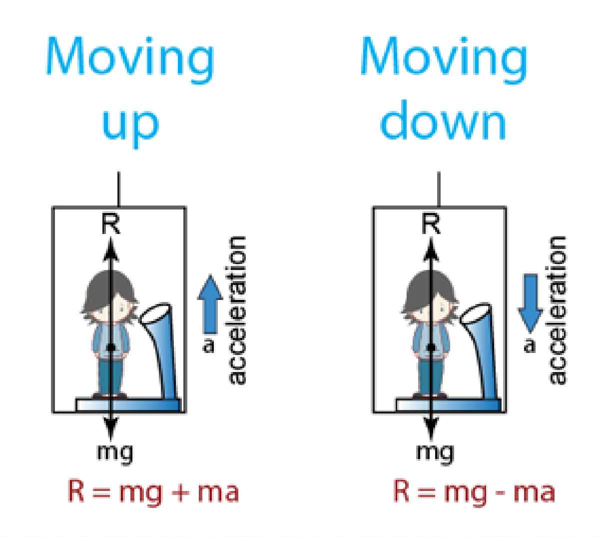
$$\sum F_y = T + (-w) = ma_y$$

$$T = w + ma_y$$

$$= 800(9.80 + 2.00) = 9440 \text{ N}$$

Apparent Weight

- "Weight" can change: You feel heavier standing in an elevator that accelerates upward as it moves toward a higher floor. If you have a bathroom scale at the time, the scale will show that you are heavier in this situation. Are you heavier?
- R is your apparent weight
  - Summation of forces: $R - mg = ma$



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