

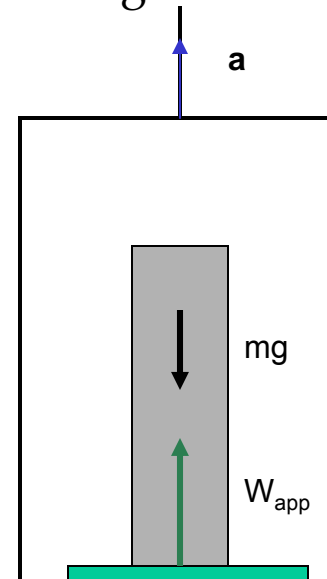
# Gravitational force

- All masses exert attractive forces on each other called *gravitational forces*.
- The most important gravitational force for this course will be the gravitational force the Earth exerts on objects.
- This force is always directed towards the center of the Earth (which can be approximated as the ground in many situations).
- The magnitude of this force is  $F_g = W = mg$  ( $g = 9.8\text{m/s}^2$ ) is called weight.  
(strictly speaking, similar to free fall acceleration, it depends on elevation)
- The *apparent weight* of an object is the magnitude net force required to prevent the object from falling freely in a non-inertial reference frame.

ex. A scale in an elevator at rest measures the *weight* of an object.

When the elevator accelerates upwards, the reading will now show the *apparent weight* of the object.

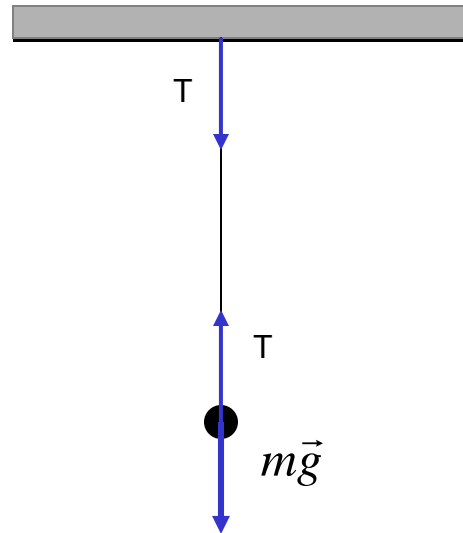
$$ma = (W_{app} - mg) \Rightarrow W_{app} = m(g + a)$$



# Tension

- *Tension* is a force in ropes (cord, chain, etc) which acts to oppose stretching; tension forces only *pull*.
- We will often make the assumption that ropes are *massless* and *unstretchable*. In this case, the magnitude of the tension is the same everywhere in the rope.
- The direction of the tension force is opposite to the direction the rope would stretch. This direction can be changed by using *pulleys*.  
ex. If we hang a 10 kg mass from the ceiling from a piece of rope, the tension in the rope at the mass is pointed upwards, but the tension in the rope at the ceiling is pointing downwards.

$$F_{net,y} = T - mg = 0 \Rightarrow T = mg$$



# Newton's Third Law

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- *Newton's Third Law*: When two objects interact, the forces on the objects from each other are *equal* in magnitude and *opposite* in direction.
- If object A exerts a force on object B ( $\mathbf{F}_{AB}$ ), then object B will exert a force on object A ( $\mathbf{F}_{BA}$ ). Furthermore,  $\mathbf{F}_{BA} = -\mathbf{F}_{AB}$ .  
ex. A book of mass  $m$  is resting on a table. The table exerts a force  $mg$  *upwards* on the book (normal force). Newton's 3rd law states that the book exerts a *downwards* force  $mg$  on the table.
- Note that  $\mathbf{F}_{AB}$  and  $\mathbf{F}_{BA}$  act on *different* objects.  
ex. In the above example, the force exerted by the table acts on the *book*, which the force exerted by the book acts on the *table*.
- $\mathbf{F}_{AB}$  and  $\mathbf{F}_{BA}$  are sometimes referred to as *action-reaction* forces.
- As a consequence of Newton's Third Law, there are no *single isolated forces* in the universe.

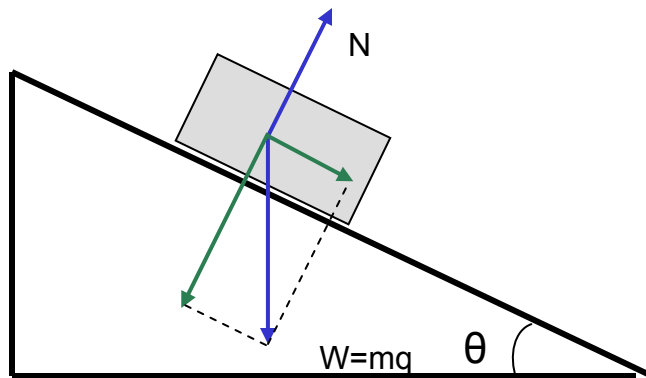
# Normal force

- The *normal force* is a contact force between solid objects. It is *perpendicular* (normal) to the surface at the point of contact, and acts to keep the objects from passing through each other.

ex. Gravity exerts a downwards force on a book sitting on a table.

The reason the book does not accelerate downwards is that the table exerts a normal force upwards on the book.

- Normal forces only *push*.
- Microscopically, the normal force arises from the (possibly very small) elastic deformation at the point of contact.
- Note that the normal force is not necessarily equal to the weight.
- Normal forces will always come in action-reaction pairs, but remember the action and reaction forces act on different objects.



# Free body diagrams

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- The first step to solving force problems is to draw a free body diagram.
- A free body diagram (FBD) is a sketch showing the object together with all the forces acting on the object.
  - A. Draw the object (simply put a dot on the paper in this section).
  - B. For each force acting on the object, draw a vector arrow with the tail on the object and pointing in the direction of the force.
  - C. Label these vector arrows with the appropriate force
  - D. Do NOT put accelerations on the free body diagram
  - E. Sketch your coordinate system ( $x, y, z$  directions) next to the object
- You can now use your free body diagram to set up the force equations using Newton's Second Law ( $\mathbf{F}_{\text{net}} = \mathbf{F}_1 + \mathbf{F}_2 + \dots + \mathbf{F}_N = m\mathbf{a}$ ). You should have one arrow on your FBD corresponding to each separate force ( $\mathbf{F}_1, \dots, \mathbf{F}_N$ ).

# External and internal forces

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- In the context of free body diagrams, the word *object* refers to any collection of *rigidly connected bodies constrained to move together*. Note that one can also use the word *system* to denote these rigidly connected bodies
  - ex. A trailer and car hitched together could be considered a single object. If the trailer is detached, the car and trailer must be considered as separate objects.
- Forces between two bodies in the same object (system) are called *internal forces*.
  - ex. The force that the car exerts on a hitched trailer and the force that the hitched trailer exerts on the car are internal forces.
- Forces on the object exerted by bodies outside the system are *external forces*.
  - ex. The force that the road exerts on the car/trailer object is an *external force*.
- Only *external forces* should be drawn on free body diagrams.
- If there are multiple objects present, a *separate* free body diagram is required for each object.

# Solving force problems

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1. Draw a free body diagram for each object. If there are multiple objects present, be sure to include all Newton's Third Law force pairs.
2. For each object, write down  $\mathbf{F}_{\text{net}} = m\mathbf{a}$ . The forces are drawn on your free body diagram. The acceleration may be given in the problem, or you may need to leave it as an unknown for now.
3. Break up  $\mathbf{F} = m\mathbf{a}$  into component form. Note that in principle you can use different coordinate systems (having different base components) for each FBD.
4. Simultaneously solve the  $\mathbf{F} = m\mathbf{a}$  equations for every object in the problem.

**Note 1:** For objects connected by a (*massless, unstretchable*) rope, the *magnitude of tension* is the same everywhere in the rope, but the direction may be different.

**Note 2:** For objects connected by a (*massless, unstretchable*) rope under tension, the *magnitude of acceleration* will be the same, but the directions may be different.

**Note 3:** The *magnitude of the normal force* is determined by the requirement that the objects to not accelerate into one another (although they may accelerate apart).