

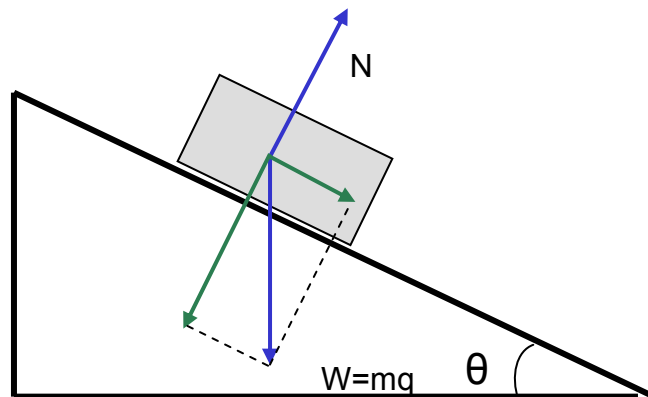
Normal force

- 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.

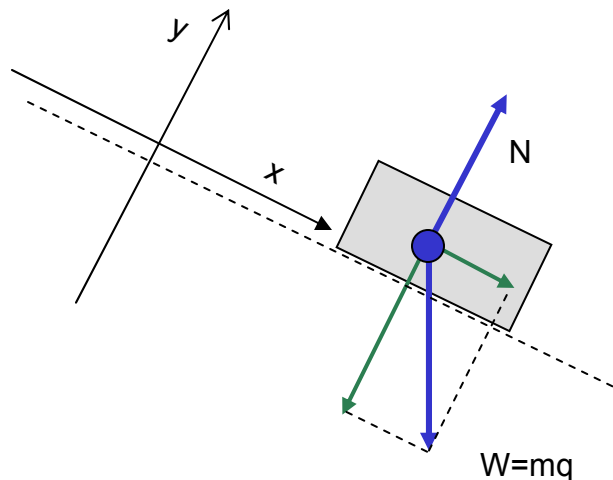


$$N = mg \cos \theta$$

$$a = g \sin \theta$$

Free body diagrams

- 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

- 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

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).

Friction

- *Frictional forces* occur when objects are in *contact* with each other. Friction exerts a force to *oppose* the objects *sliding* against each other (so they have the same relative velocity).
- The *static frictional force* arises when the two objects are at *rest* relative to one another.
 - ex. You try push a heavy crate horizontally across the floor. The crate does not move because a *static frictional force* between the floor and crate is exerted on the crate to stop it from sliding.
- The *kinetic frictional force* arises when the two objects have a *non-zero relative velocity* (but are still in contact).
 - ex. If you slide a book across the table, it will slow down because of the *kinetic frictional force* between the table and book.
- Microscopically, frictional forces arise because surfaces are rough on very small length scales and due to molecular forces between two object in very close contact.

Magnitude of friction

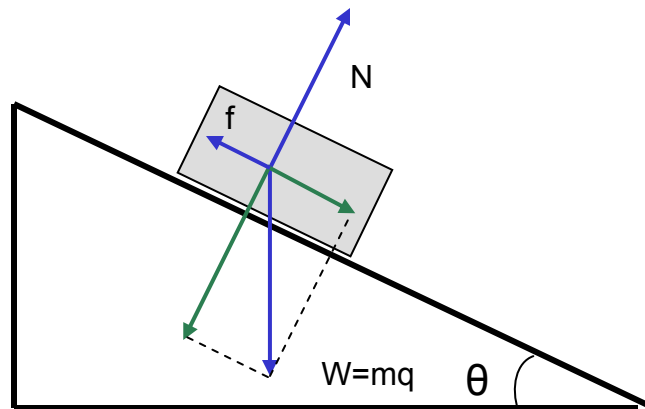
- If the two objects in contact are pressed together more firmly, the frictional forces will increase. Microscopically, more of the rough surfaces cold-weld to each other.
- The (maximum) magnitude of the frictional force is proportional to the *normal force*, with the constant of proportionality called the *coefficient of friction*.

Static Friction

- Static friction does not have a predetermined value, but depends on the other forces acting on the object, according to the following rules:
 - A. If the two objects remain relatively at rest, the static friction f_s and the component of F parallel to the surface balance each other out.
 - B. The maximum magnitude of the static frictional force is $f_{s,\max} = \mu_s F_N$.
- If the magnitude of component of force along the surface *exceeds* $f_{s,\max}$, the object will begin to slide; $f_s = \mu_s F_N$ when the objects are on the *verge* of slipping.

Kinetic Friction

- If an object is sliding along a surface, a *kinetic frictional force* will be exerted by the surface on the object to oppose this motion.
- The *magnitude* of the kinetic frictional force is $f_k = \mu_k F_N$.
- The values of μ_s and μ_k depend on the two surfaces in contact. Very roughly, μ_s and μ_k can range from 0 (frictionless contact) to ~ 1.5 .
 - ex. The coefficient of kinetic friction between wet ice sliding on wet ice is much smaller than the coefficient of kinetic friction between rubber tires and asphalt.
- The *direction* of the frictional force acts to oppose relative motion between the object and surface.
 - ex. A box remains at rest on a concrete floor. If we exert a force of 5N pushing the box left, the force of static friction is 5N to the right. If we exert a force of 5N pushing the box right, F_s is 5N left.



$$N = mg \cos \theta$$

$$a = g \sin \theta - \mu_k g \cos \theta$$