Force and Motion

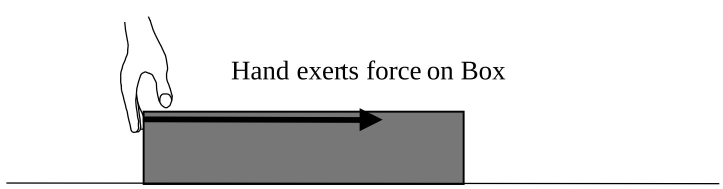
- Concept of Force
- Newton’s Three Laws
- Types of Forces
- Free body analysis
  - Equilibrium
  - Nonequilibrium
- Friction
- Problem Solving

Force

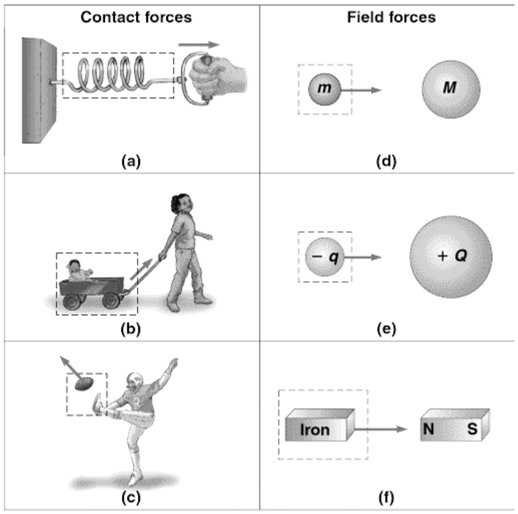
A ***Force*** is a push or a pull that is exerted *on* an object *by* some other object.

Forces can arise when two objects touch each other (but some forces act over a distance)

Forces are ***vector*** quantities!



Classifying Forces



Contact forces can arise when one thing actually touches another as in the case of (a) a force transmitted through a solid spring or (b) the handle of a wagon, or (c) the momentary contact between foot and football.

Field forces are a forces that can act "at a distance." Examples are (d) the gravitational force that one mass exerts on another, (e) the electrostatic force that one charge exerts on another, and (f) the magnetic force that a magnet exerts on a piece of iron.

Classifying Forces

Four Basic Forces of Nature:

1) Strong Nuclear Force

2) Electromagnetic Force

3) Weak Nuclear Force

4) Gravitational Forces

We can classify and quantify these forces by measuring their effects in nature in the context of Newton's Laws of motion.

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Newton's First Law

1) An object at rest remains at rest, and an object in motion continues in motion with constant velocity (that is, in a straight line with constant speed) unless it experiences a net external force.

This principle notes that the tendency of any object is resist any change in its motion (i.e., to resist acceleration)

"***net external force***" means "the vector sum of all the forces that act on an object."

$$\text{If } \Sigma F = 0, \text{ then } a=0$$

The tendency to resist change in motion is called ***inertia***. The measure of an object's inertia is its mass.

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Newton's 2nd Law

2) The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass

In equation form, this is expressed by the well-known

$$\Sigma F = ma$$

which is really 3 equations...

$$\Sigma F_x = ma_x,\ \ \Sigma F_y = ma_y,\ \ \Sigma F_z = ma_z$$

one for each scalar component of the vector net force.

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Newton's 2nd Law

The relationship between force, mass and acceleration depicted by Newton's 2nd Law suggests a natural unit for force:

$$[F] = [m][a] = M\ L/T^2$$

The ***SI unit of force*** is the ***newton***(N)

$$1\ N = 1\ kg \cdot m/s^2$$

So, force and mass have different units. An object's mass is a measure of its inertia. An object's weight is a measure of how much gravitational force the earth exerts on that object.

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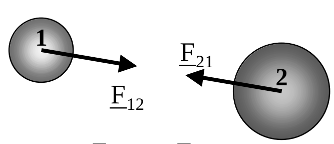
Newton's Third Law

3) If two objects interact, the force exerted on object 1 by object 2 is equal in magnitude but opposite in direction to the force exerted on object 2 by object 1.



$$\underline{F}_{12} = -\underline{F}_{21}$$

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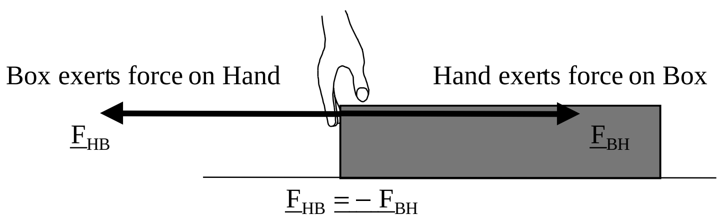
Newton's Third Law

All forces come in pairs!

If an action force acts on one object, there is a reaction force that acts on another object.

The reaction force NEVER acts on the same object that the action force does!!



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Newton's Laws of Motion

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3) If two objects interact, the force exerted on object 1 by object 2 is equal in magnitude but opposite in direction to the force exerted on object 2 by object 1.

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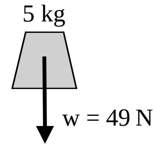
Types of Forces

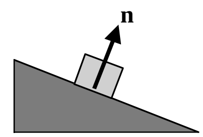
1) ***Weight***

An object of mass m, near the surface of the earth is subject to a weight force, ***w=mg***. This force is directed vertically downwards towards the ground.



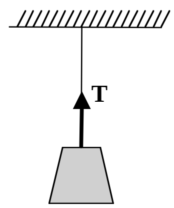
2) ***Normal Force***

If two objects are in contact, they may each exert a force on the other. The component of this contact force that is perpendicular (normal) to the surfaces in contact is called a normal force. Normal forces are always tend to push to objects apart, never pull them together



3) ***Tension Force***

Cables, strings and ropes can all exert a tension force on the object to which the rope is attached. This force is directed along the line of the rope and is the same magnitude throughout the length of a (massless) rope. The direction of the rope may be changed by a pulley, which will change the direction of the force, but not its magnitude.



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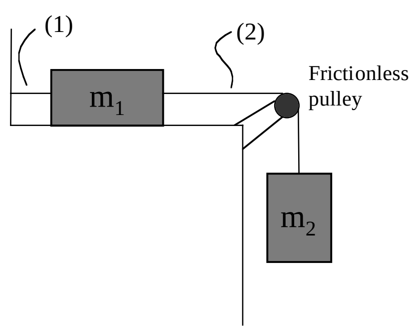
Free Body Analysis

Free body analysis is a recipe for determining all the forces that act on a mechanical system, and then determining how the motion of the mechanical system is affected by these forces.

Equilibrium Example:
A mass, m_1, sits on a horizontal frictionless surface. It is attached to a wall by a horizontal cable (1) and to a hanging mass, m_2, by another cable (2) which passes over the pulley.

What is the tension force in cable (1) and what is the tension force in cable (2)?



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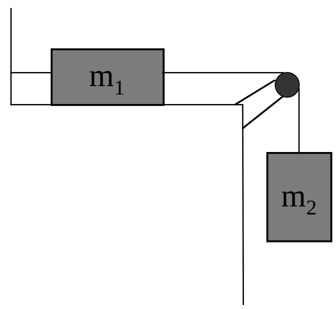
Blocks and pulley at rest

- Draw a picture
- Identify the system
- Identify Interactions
- Draw Forces
- Declare Acceleration
- Choose Coordinate axes
- Solve Newton's 2nd Law Equations

Equilibrium



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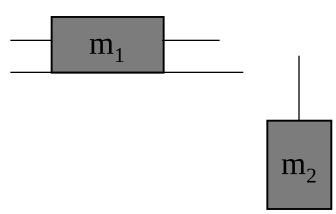

Two separate systems

Each mass is a system!

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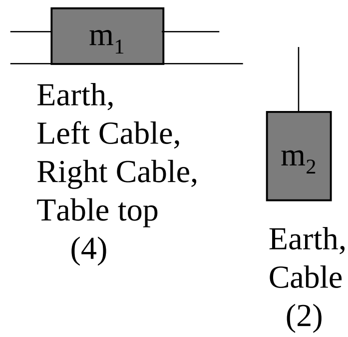

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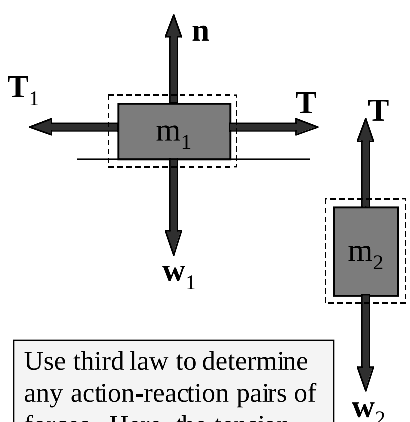

Use third law to determine any action-reaction pairs of forces. Here, the tension force, T, is the same on each block.

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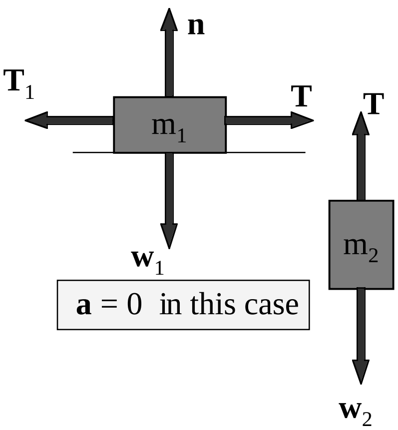

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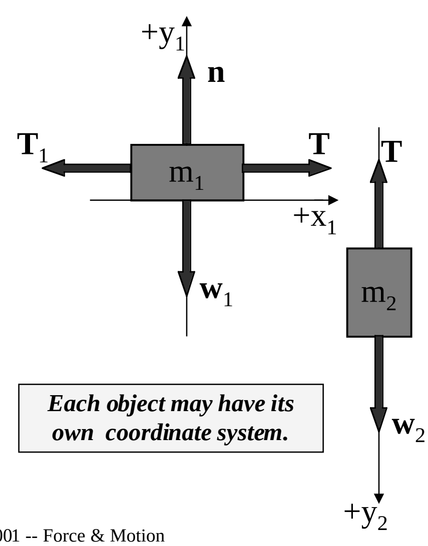

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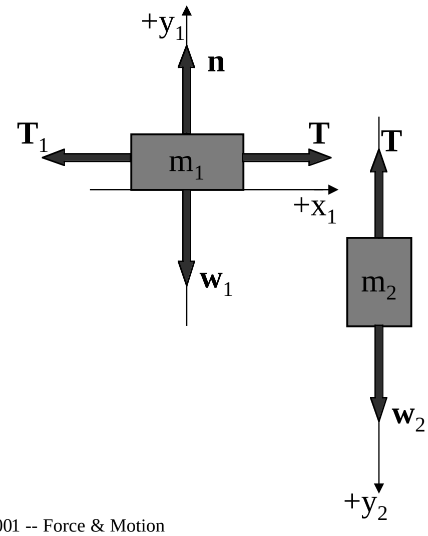

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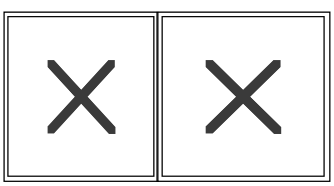
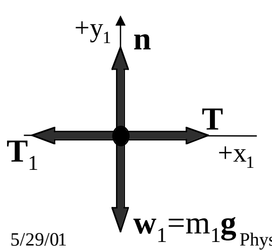
Blocks and pulley at rest

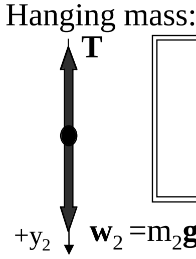
Solve Newton's 2nd Law Equations

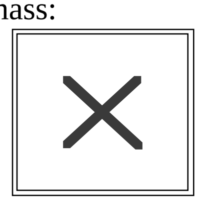
Sliding mass:





Hanging mass:





Conclusion:

$T_1 = T = w_2 = m_2g$

The tension in each rope is equal to the weight of the hanging mass.

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Blocks and pulley in motion

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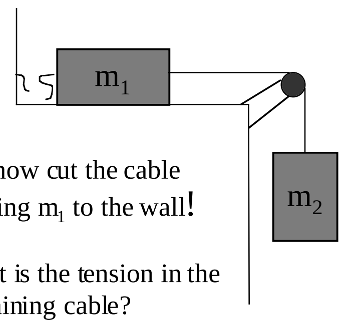
Non-equilibrium



We now cut the cable holding m_1 to the wall!

What is the tension in the remaining cable?

What is the acceleration of the blocks, m_1 and m_2 ?

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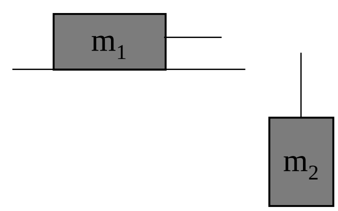

Two separate systems

Each mass is a system!
…. as before!

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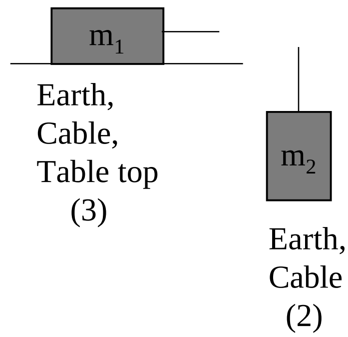

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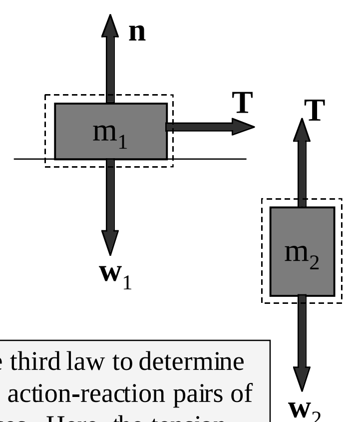

Use third law to determine any action-reaction pairs of forces. Here, the tension force, T, is the same on each block.

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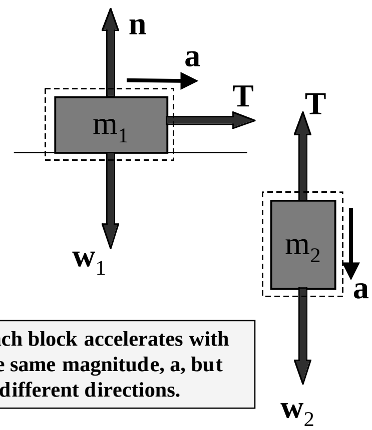

Each block accelerates with the same magnitude, a, but in different directions.

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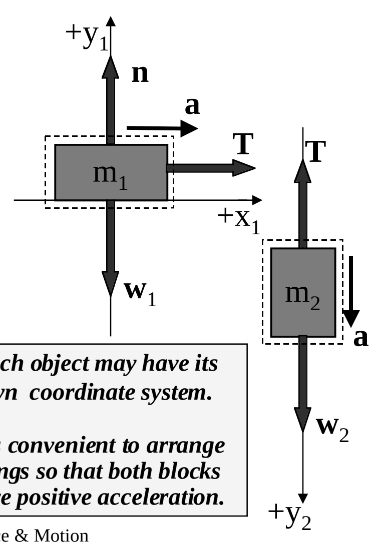

Each object may have its own coordinate system.

It is convenient to arrange things so that both blocks have positive acceleration.

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Blocks and pulley in motion

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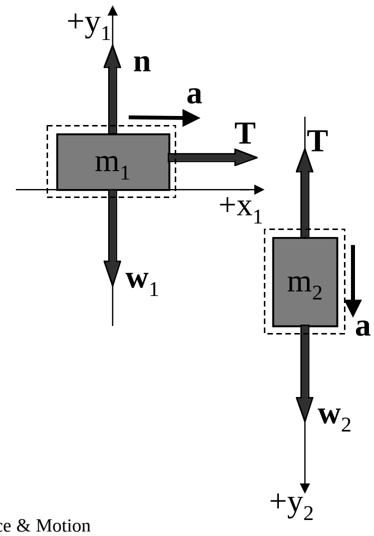

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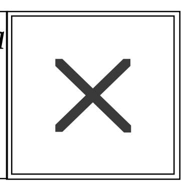
Blocks and pulley in motion

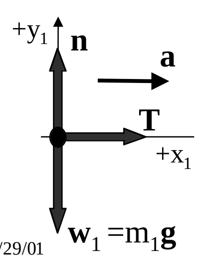
Solve Newton's 2nd Law Equations

Sliding mass:

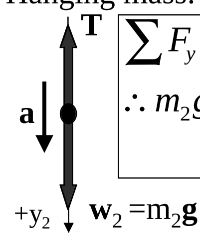
$$\sum F_x = m_1 a$$

$$\therefore T = m_1 a$$





Hanging mass:



$$\sum F_y = m_2 a$$

$$\therefore m_2 g - T = m_2 a$$

Conclusion: Two equations in two unknowns (T, a)

$T = m_1 a$

$m_2 g - T = m_2 a$

Solutions:

$$a = \frac{m_2 g}{m_1 + m_2}$$

$$T = \frac{m_1 m_2 g}{m_1 + m_2}$$

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Friction

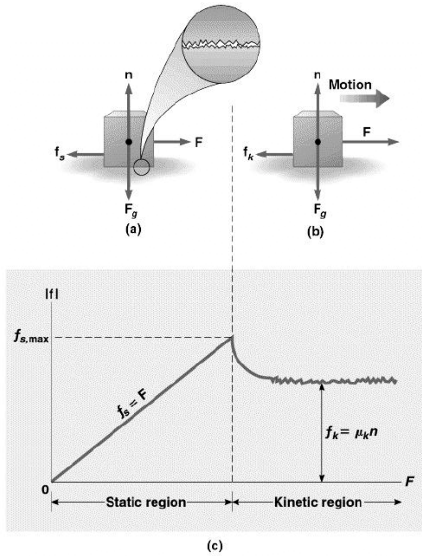
a) ***static friction***
Two surfaces in contact resist the tendency to begin sliding over each other. This resistance force is called static friction, f_s

There is a maximum amount of static friction that can be provided between two surfaces. Its magnitude depends only on the nature of the materials in contact and how firmly they are pressed together.

$f_{s,max} = \mu_s n$
μ_s: coefficient of static friction
n: normal force

b) ***kinetic friction***
Once $f_{s,max}$ is exceeded, the two surfaces begin to slide over each other, but they don't slide freely. The sliding motion is resisted by the force of kinetic friction , f_k.

The magnitude of f_k is given by:
$f_k = \mu_k n$
μ_k: coefficient of kinetic friction
n: normal force



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Friction

Table*: *Coefficients of friction*

	μ_s	μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete	1.0	0.8
Wood on wood	0.25-0.5	0.2
Glass on glass	0.94	0.4
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	----	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.1	0.03
Teflon on teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

**Approximate values*

The magnitude of the frictional force depends on the nature of the two surfaces that are in contact.

Some materials are more sticky or slippery than others. The stickiness is expressed by the dimensionless coefficient of friction.

Lots of friction between rubber and concrete

Low friction in synovial joints

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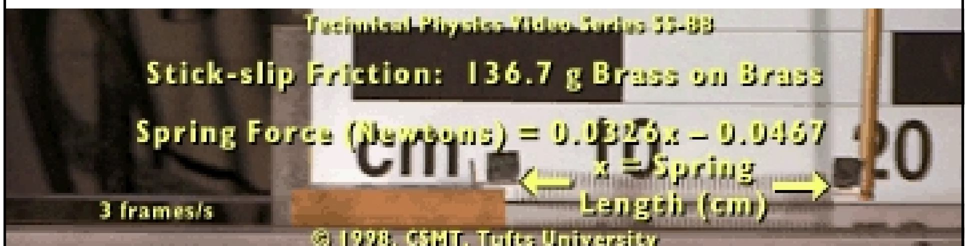
Friction

Stick-slip Friction for brass on brass



A brass brick is placed on the bed of a milling machine (also made of brass.) The bed moves at constant speed to the left and drags the brick with it until the force exerted by the spring (attached to the brick) exceeds $f_{s,max}$, at which point, the brick slides to the right until static friction takes over again and the brick sticks to the bed again and the process repeats.

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