Ch.4 Forces

Conceptual questions #1, 2, 12

Problem 1, 2, 5, 6, 7, 10, 12, 15,

16, 19, 20, 21, 23, 24, 26, 27, 30, 38, 39, 41, 42, 47, 50, 56, 66

Forces

Forces - vector quantity that changes the velocity vector of an object. When you hit a baseball, the velocity of the ball changes.

Can be a push or a pull on an object

Contact forces – result from physical contact with an object (pulling a trailer, friction forces, normal force)

Field forces – interactions where contact is not necessary (electric force, gravitational force)

4 fundamental forces

Strong nuclear force – subatomic particles

Electromagnetic forces – forces between charges

Weak nuclear force – radioactive decay

Gravitational force – attraction between objects with mass (why a dropped ball falls down)

Newton’s Laws

3 Laws that govern the motion of a particle

1st Law

2nd law

3rd Law

Newton’s 1st Law

Also called law of inertia.

Objects at rest stay at rest, objects in motion continue that motion, unless influenced by an outside force.

Book’s definition:

“An object moves with a velocity that is constant in magnitude and direction, unless acted on by a nonzero net force.”

Mass and inertia

Inertia – the tendency of an object to continue in its original state of motion.

Mass – measurement of an object’s resistance to change in motion due to a force.

The more massive an object, the more inertia the object will have.

An 18-wheeler has a lot more inertia than a small car. It’s harder to stop the 18-wheeler.

Determining Inertia/Mass

We measure the mass of an object.

The U.S. unit is the slug

The SI unit is kilogram (kg)

We will exclusively use the SI units

mass of a small car ~1000 kg

mass of a cat ~4 kg

mass of a penny ~1 gm

The more mass an object has, the more force is needed to change it’s velocity (accelerate the object).

Kick a volleyball – it will move a lot

Kick a bowling ball – it won’t move as much

The bowling ball resists changing its velocity more than the volleyball. The bowling ball has more inertia (a higher mass).

Newton's 2nd Law

Book's definition:

The acceleration, **a**, of an object is directly proportional to the net force acting on it and inversely proportionally to its mass.

equation: $\mathbf{a} = \Sigma \mathbf{F}/m$

or: $\Sigma \mathbf{F} = m\mathbf{a}$, the Σ, here means the sum of the forces, or the adding up of all the force vectors which are exerted on an object.

Newton's 2nd Law

Remember that $\Sigma \mathbf{F} = m\mathbf{a}$, is a vector equation.

We can write the 2nd law with 3 component equations.

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

The 2nd law can be applied in the 3 dimensions individually.

If there is no net force, the acceleration is zero, then the velocity is constant.

Newton's 3rd Law

Book definition:

If object 1 and object 2 interact, the force F_{12} exerted by object 1 on object 2 is equal in magnitude but opposite in direction to the force F_{21} exerted by object 2 on object 1.

Law of equal and opposite reaction

(If you push on a wall, the wall pushes back onto you.)

Quick Quiz #4.1

Units of forces

Units of forces are the pound (US) and the newton (SI). We will use the newton.

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

To convert:

1 N = 0.225 lb 1 lb = 4.45 N

Also of use: 1 kg of mass weighs 2.2 lbs.

Notice that the weight is equal to mass x gravity

A 200 pound person weighs 890 N.

$$200lbs \times \frac{1kg}{2.2lbs} \times 9.8m/s^2 = 890N$$

(9.8/2.2 gives us the 4.45 used to convert from pounds to newtons)

Some weights in newtons

Weight of a truck, 5000 lbs

$$5000lbs \times \frac{1kg}{2.2lbs} \times 9.8m/s^2 = 22272N$$

Or 22 kN

Weight of Earth.

Mass of Earth is 5.98×10^{24} kg

So its weight is $(5.98 \times 10^{24}$ kg$)(9.8 m/s^2) = 5.86 \times 10^{25}$ N

58600000000000000000000000 N

Example

The propeller of a boat motor exerts a force of 200 N on 500 kg boat. What will the boat's acceleration be?

Use 2nd Law **$F = ma$**

200 N = (500 kg)a

$a = (200\ N)/(500kg) = 0.4\ m/s^2$

What if the boat's mass doubled (m = 1000 kg)?

$a = (200\ N)/(1000\ kg) = 0.2\ m/s^2$

Examples of forces we will work with

- Gravitational force – due to gravity
- Normal force – due to contact
- Friction forces
- Spring forces – compressing or stretching a spring
- Tensions – involving ropes, cables…

Gravitational force

Gravitational force is the mutual attraction between any two objects in the Universe.

Determined by $F_g = Gm_1m_2/r^2$
(r is the separation between the two objects)

Gravitational constant $G = 6.67 \times 10^{-11}\ Nm^2/kg^2$
We will use this more later.

Gravitational Force

$F_g = Gm_a m_b/r^2$ Letting m_b equal the mass of the Earth and r the radius of the Earth we get:

$$F_g = \frac{(6.67 x 10^{-11} Nm^2/kg^2)(5.98 x 10^{24} kg) m_b}{(6.38 x 10^6 m)^2}$$

$F_g = (9.8 \text{ m/s}^2) m_b = m_b g$

Weight

$w = mg$, where $g = Gm_E/r^2$

Gravitational Force

Find the weight of a 100 kg person standing at:

Sea level. $r = r_e = 6.38x10^6$m

On top of Mt. Everest $r = r_e + 10000$m

In spacecraft $5x10^6$m above Earth, $r = 11.38x10^6$m

Sea level: $r = r_e = 6.38 \times 10^6 m$

$w = m_p g = m_p (Gm_E/r^2) = 100\ kg(9.8 m/s^2)$

$w = 980\ N$ (220.2 lbs)

Mt. Everest: $r = r_e + 10^5 m = 6.39 \times 10^6 m$

$w = m_p g = m_p (Gm_E/r^2) = 100\ kg(9.77 m/s^2)$

$w = 977\ N$ (219.5 lbs)

Spacecraft: $r = 11.38 \times 10^6 m$

$w = m_p g = m_p (Gm_E/r^2) = 100\ kg(3.08 m/s^2)$

$w = 308.0\ N$ (69.2 lbs)

On the Moon

On the surface of the moon, $g = g_{moon} = 1.62 m/s^2$

What would a 100 kg person weigh on the moon?

$$w = (100kg)(1.62 m/s^2) = 162\ N$$

or 36.4 pounds

Normal Forces

- Normal forces, are contact forces that are normal, or perpendicular, to the surface in contact.

  Say you have a 10 N brick sitting on a table. The Earth pulls down on the brick with a force of 10 newtons. If there was no normal force, the brick would fall through the table. The table exerts a 10 N normal force upon the brick.

Normal Forces

Example: My weight is 827 N pressing down on the floor. The floor exerts a normal force of 827 N up on me.

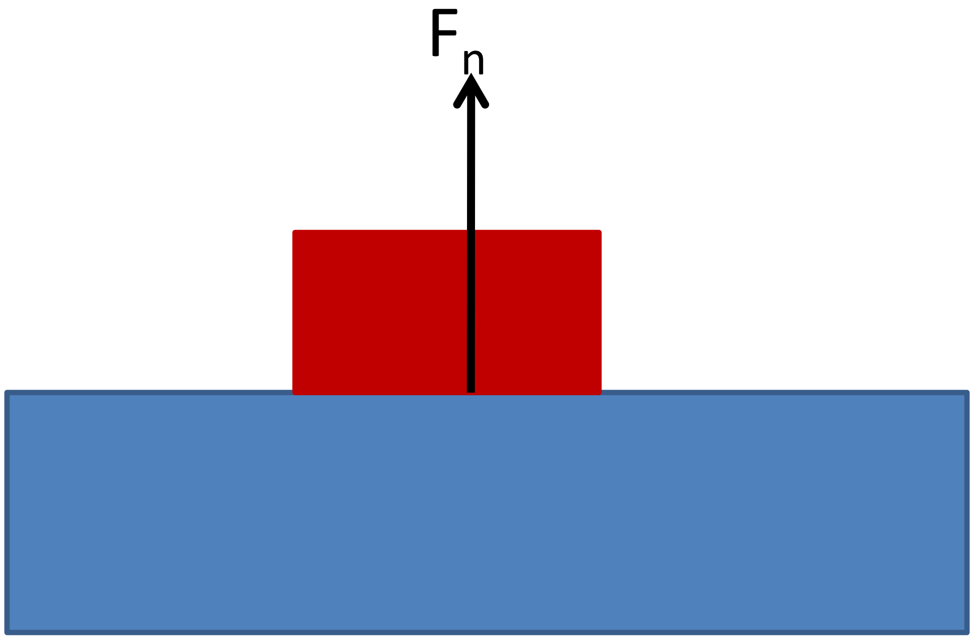
In general $|F_n| = m\mathbf{g} \cos \theta$

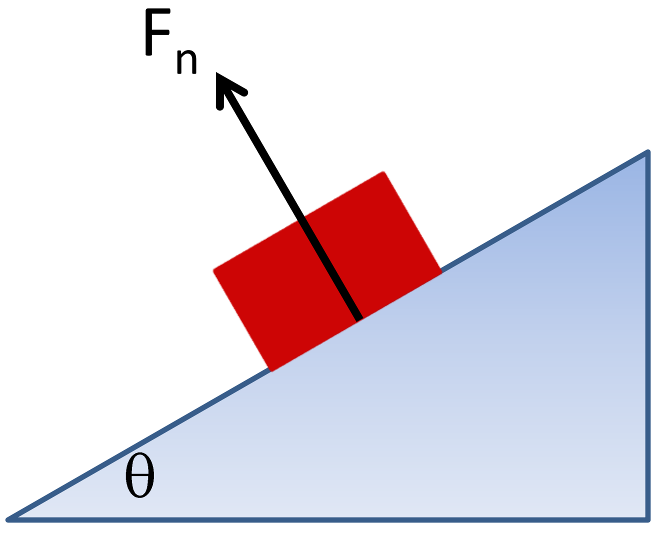
The magnitude of the normal force is equal to that of the weight when an object is on a horizontal surface. $\theta = 0$. (cos 0 = 1)

$|F_n| = mg$

Normal Forces

Normal forces are always perpendicular to the surface, and object is pressed against.

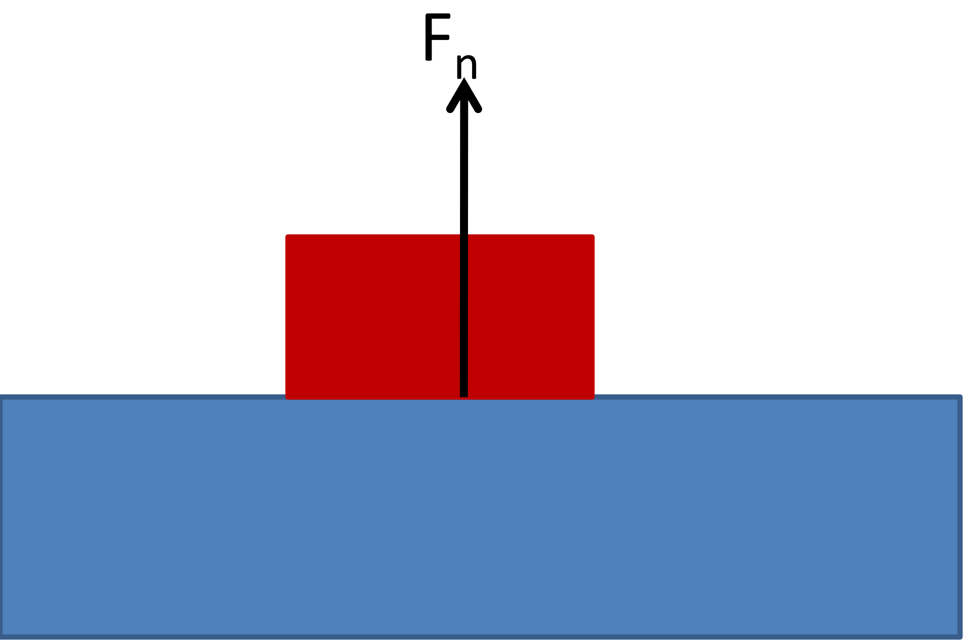




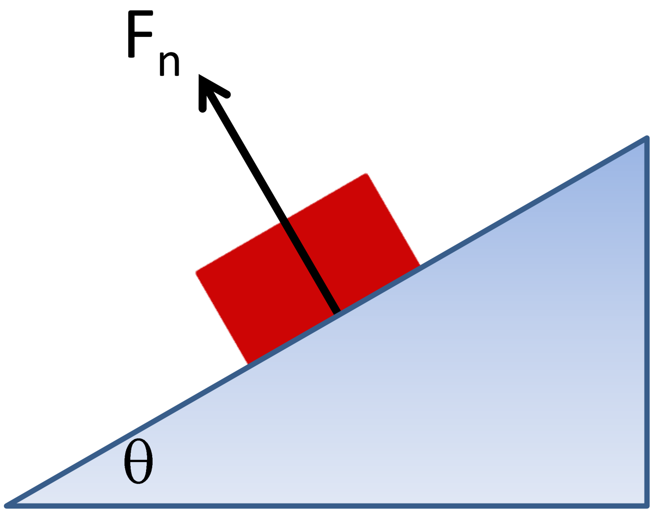
Normal Forces

The Red block has mass, m

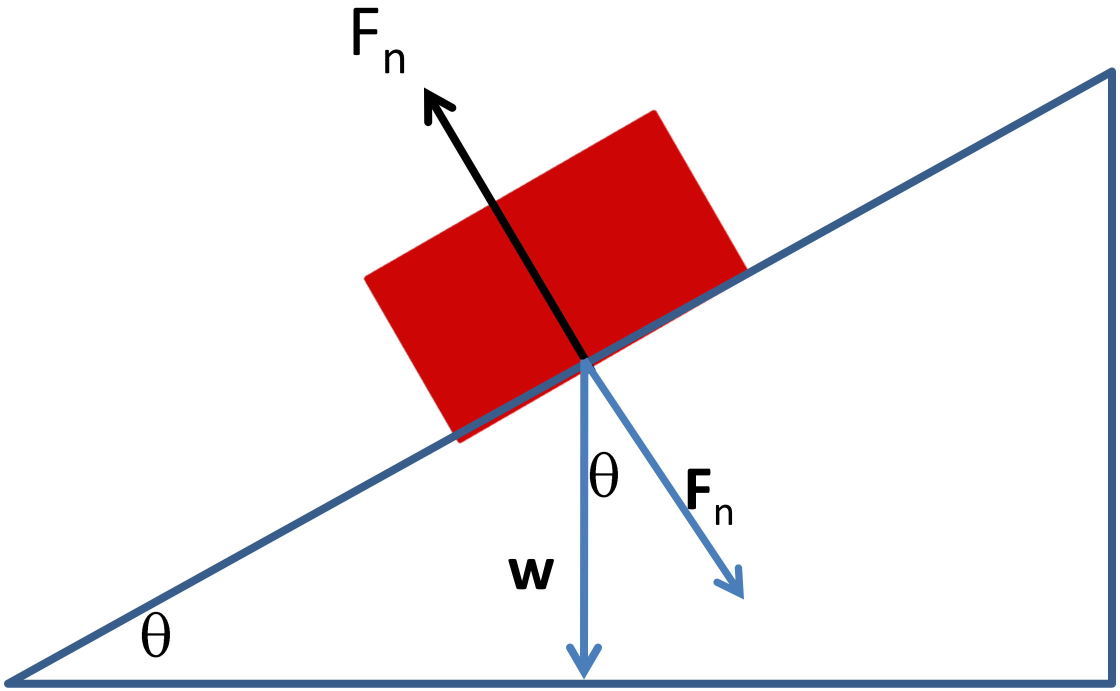
$\mathbf{F}_n = m\mathbf{g} \cos 0 = m\mathbf{g}$

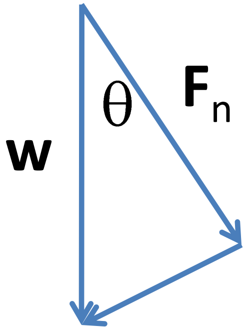


$\mathbf{F}_n = m\mathbf{g} \cos \theta$



Trig trick

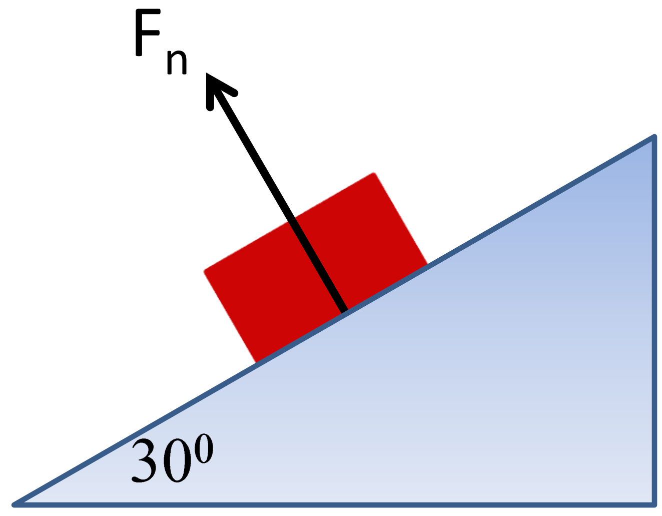




- F_n is the adjacent component of the weight

Normal Forces

Let the mass of the block be 50 kg.



$w = (50\ kg)(9.8 m/s^2) = 490\ N$

$F_n = (50\ kg)(9.8 m/s^2) \cos 30 = 424\ N$

Normal Forces

What happens when we increase θ from 0 to 90 degrees?

$F_n = (50\text{ kg})(9.8\text{m/s}^2)\cos\theta$

$F_n = (50\text{ kg})(9.8\text{m/s}^2)\cos 0 = 490\text{ N}$

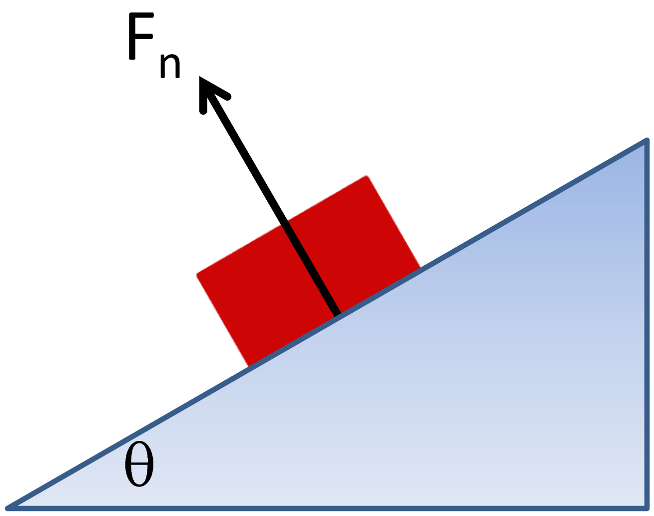
$F_n = (50\text{ kg})(9.8\text{m/s}^2)\cos 10 = 483\text{ N}$

$F_n = (50\text{ kg})(9.8\text{m/s}^2)\cos 30 = 424\text{ N}$

$F_n = (50\text{ kg})(9.8\text{m/s}^2)\cos 45 = 346\text{ N}$

$F_n = (50\text{ kg})(9.8\text{m/s}^2)\cos 60 = 245\text{ N}$

$F_n = (50\text{ kg})(9.8\text{m/s}^2)\cos 90 = 0\text{ N}$



Free Body Diagrams

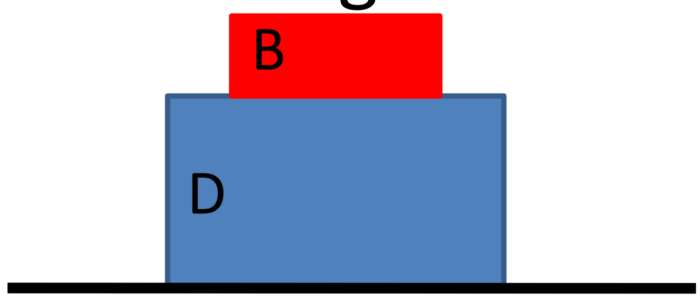
A free body diagram is a picture that includes an object, and ALL the forces that are exerted on the object.

We will use these a lot because they are very handy. If you set up the diagram correctly, the equations needed for using Newton's 2nd Law can be visualized.

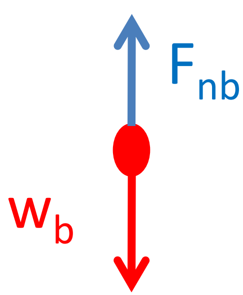
Normal Forces

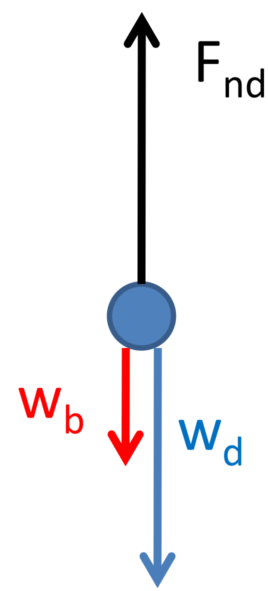
Looking at Newton's 2nd Law. $\Sigma \mathbf{F} = m\mathbf{a}$

A 10 kg book is sitting on a 20 kg desk. What normal force does the ground exert on the desk.



Free body diagrams





Since the book sits still on the desk, $\mathbf{a} = 0$.

$\Sigma\mathbf{F} = m\mathbf{a} = 0$, $\mathbf{w}_b + \mathbf{F}_{nb} = 0$ N. $\mathbf{w}_b = -\mathbf{F}_{nb}$

Also the desk sit still on the ground, $\mathbf{a} = 0$.

$\Sigma\mathbf{F} = m\mathbf{a} = 0$, $\mathbf{w}_b + \mathbf{w}_d + \mathbf{F}_{nb} = 0$ N.

$\mathbf{w}_b + \mathbf{w}_d = -\mathbf{F}_{nb}$

(remember that forces are vectors)

$\mathbf{F}_{nb} = -m_b\mathbf{g} = (10\text{ kg})(9.8\text{m/s}^2) = 98$ N upward.

$\mathbf{F}_{nd} = -m_b\mathbf{g} - m_d\mathbf{g}$

$= (10\text{ kg} + 20\text{ kg}))(9.8\text{m/s}^2) = 294$ N upward

Notice that to find the normal force the ground exerts on the desk, you use the weight of the book and the desk.