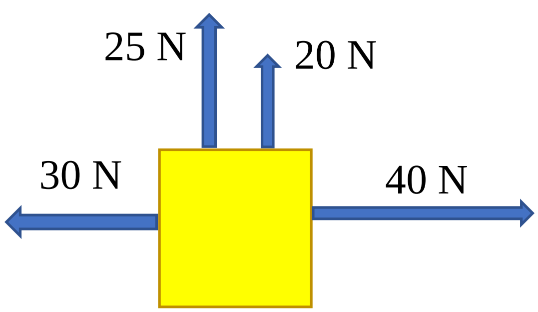
Name: ____ Date: _______

PHYSICS
UNIT 3: FREE BODY DIAGRAMS & APPLIED FORCES

Free Body Diagrams

Free body diagrams are drawings that show a simplistic representation of a real-life object (represented as a square or circle) with all the forces that simultaneously act it. All forces on the free body diagram are represented by vector arrows. The tip of the arrow indicates the direction of the forces' influences and the lengths of the arrows indicate the forces' magnitudes. The values of the forces' magnitudes are often written next to their respective arrows.

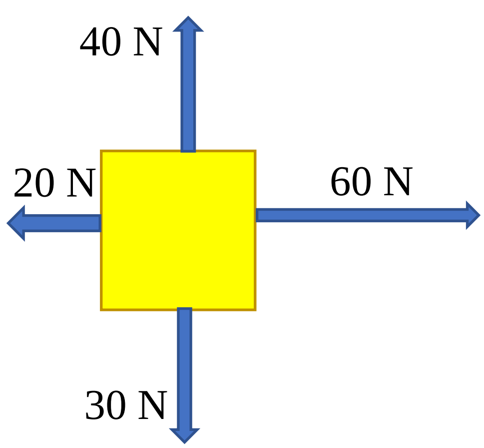
Illustrative Example 1



The free body diagram to the left shows an object (represented by a square) that is simultaneously affected by four different forces.

- 30 N west (-30 N)
- 25 N north (+25 N)
- 20 N north (+20 N)
- 40 N east (+40 N)
- 0 N south (not shown)

Note that the lengths of the vector arrows are proportional to the forces' magnitudes. Stronger force = longer arrow.



The free body diagram to the left shows an object (represented by a square) that is simultaneously affected by four different forces.

- 40 N north (+40 N)
- 60 N east (+60 N)
- 30 N south (-30 N)
- 20 N west (-20 N)

Note that the lengths of the vector arrows are proportional to the forces' magnitudes. Stronger force = longer arrow.

The Net Force

The **net force** (or **resultant force**) is the one force acting upon an object when all forces are added together and all but one force cancels out. The net force is the one "leftover force", and the acceleration of the object will always be in the direction of the net force. The net force is the "overall effect" when all of the forces are added together.

If all the forces acting on an object when added together cancel each other out, the forces are balanced forces. The net force is 0 N. Under balanced force conditions, the object will not accelerate—the object will keep its original state of motion. Objects in motion will continue to move at a constant velocity (rate and direction). Objects at rest will remain in a state of static equilibrium.

If all the forces when added together do not cancel each other out, the forces are unbalanced forces. The net force is a value other than 0 N. The object will accelerate in the direction of the net force. The magnitude of the acceleration is proportional to the net force—the greater the net force, the greater the acceleration. Objects in motion will get faster with time, or get slower with time, or change direction. Objects initially at rest will begin to move in the direction of the net force.

The net force is calculated using a process of vector addition and process of elimination until one force vector remains. The one force vector remaining is the net force.

How to calculate the net force

Step 1: Identify all of the forces that act upon the body. List the forces.

- Group North and South forces together. North is the (+) direction. South is the (-) direction.
- Group East and West forces together. East is the (+) direction. West is the (-) direction.

Step 2. Determine the leftover force in the N-S transect and the leftover force in the E-W transect. When adding vectors, use the (+) and (-) for direction.

- Calculate the leftover force acting upon the object in the North and South direction. North is (+) and South is (-)

$$F_{N-S} = F_{(North)} + F_{(South)}$$

- Calculate the leftover force acting upon the object in the East and West direction. East is (+) and West is (-)

$$F_{E-W} = F_{(East)} + F_{(West)}$$

Step 3. Redraw the free body diagram using only the leftover forces that remain in the N-S transect and the E-W transect.

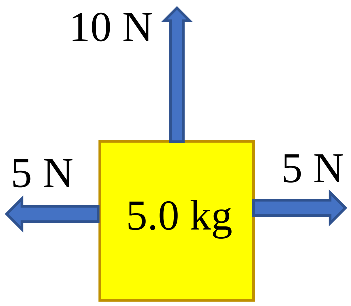
Step 4. Determine the overall net force acting upon the object.

- If one force remains because N-S or E-W cancelled themselves out, no additional calculation is needed. The net force is that one leftover force.
- If two forces remain, one in the N-S transect and one in the E-W transect, you must use the Pythagorean Theorem to determine the hypotenuse = Net force.

Step 5. Calculate the acceleration of the object by using the object's mass and the net force. Acceleration = $a = \frac{F_{net}}{m}$

Illustrative Example 1

Original free body diagram

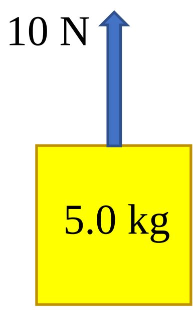


- Step 1: List the forces (there are three forces)
  10 N north; 0 N south
  5 N east; 5 N west

- Step 2: Calculate the net force in the N-S transect (add together the forces in the north and south directions).
  $F_{N-S} = +10N + 0N = \mathbf{+10N} = \mathbf{10\ N\ north}$
  Leftover force = 10 N north

- Step 2: Calculate the net force in the E-W transect (add together the forces in the east and west directions).
  $F_{E-W} = +5N + -5N = \mathbf{0N}$
  Leftover force = 0 N
  East and west vectors cancelled each other out.

Redrawn with leftover force



- Step 3: Redraw the free body diagram using only the leftover forces in the N-S and E-W transects.

- Step 4: Determine the overall net force affecting the object.

The only remaining force is the 10 N north. That is the net force. No additional step is needed.

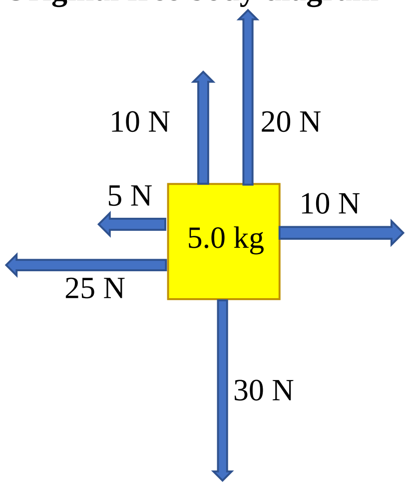
- Step 5: Calculate the acceleration affecting the object

$$a = \frac{F_{net}}{m} = \frac{10N\ north}{5.0kg} = 2.0\ {}^{m}/_{s^2}\ @\ north$$

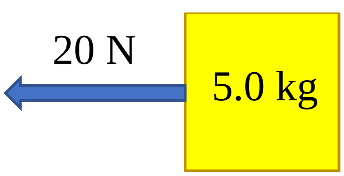
Answer: The net force affecting the object is 10 N north. The object will accelerate north at 2.0 m/s^2.

Illustrative Example 2

Original free body diagram



Redrawn with leftover force



- Step 1: List the forces (there are three forces)
  10 N north, 20 N north; 30 N south
  10 N east; 5 N west, 25 N west

- Step 2: Calculate the net force in the N-S transect (add together the forces in the north and south directions).
  $F_{N-S} = +10N + +20N + -30N =$ **0 N**
  Leftover force = 0 N
  North and south cancelled each other out.

- Step 2: Calculate the net force in the E-W transect (add together the forces in the east and west directions).
  $F_{E-W} = +10N + -5N + -25\ N = -20N$ = **20 N west**
  Leftover force = 20 N west

- Step 3: Redraw the free body diagram using only the leftover forces in the N-S and E-W transects.

- Step 4: Determine the overall net force affecting the object.

The only remaining force is the 20 N west. That is the net force. No additional step is needed.

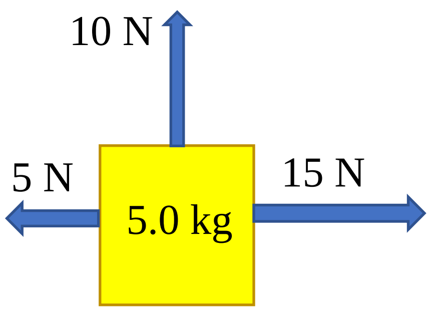
- Step 5: Calculate the acceleration affecting the object

$$a = \frac{F_{net}}{m} = \frac{20N\ west}{5.0kg} = 4.0\ {}^{m}/_{s^2}\ @\ west$$

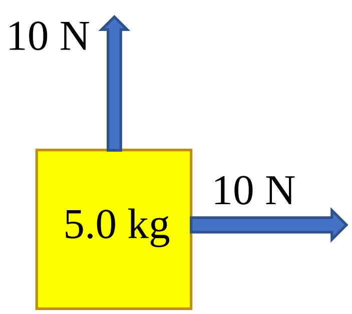
Answer: The net force affecting the object is 20 N west. The object will accelerate west at 4.0 m/s^2.

Illustrative Example 3

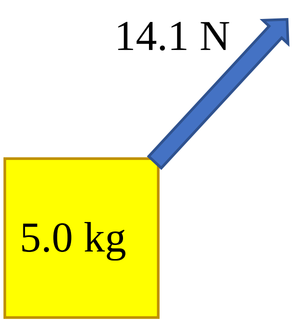
Original free body diagram



Redrawn with leftover forces



Net force



- Step 1: List the forces (there are three forces)
  10 N north; 0 N south
  15 N east; 5 N west

- Step 2: Calculate the net force in the N-S transect (add together the forces in the north and south directions).
  $F_{N-S} = +10N + 0N = +10N =$ **10 N north**
  Leftover force = 10 N north

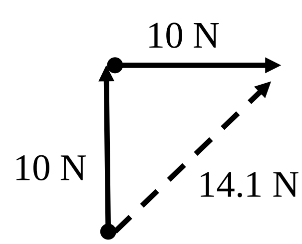
- Step 2: Calculate the net force in the E-W transect (add together the forces in the east and west directions).
  $F_{E-W} = +15N + -5N = 10N =$ **10 N east**
  Leftover force = 10 N east

- Step 3: Redraw the free body diagram using only the leftover forces in the N-S and E-W transects.

- Step 4: Determine the overall net force affecting the object. The leftover forces are 10 N north and 10 N east. They are the sides of the right triangle.

  Use the Pythagorean Theorem to solve for the net force. The net force is the hypotenuse of the right triangle.

$$C = \sqrt{(10N)^2 + (10N)^2} = 14.1\,N \;\; @ \text{ NE}$$



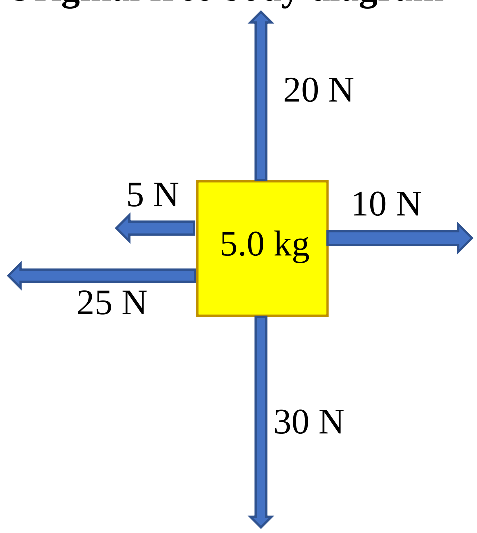
- Step 5: Calculate the acceleration affecting the object

$$a = \frac{F}{m} = \frac{14.1N}{5.0kg} = 2.82\,{}^{m}\!/_{s^2} \; @ \; NE$$

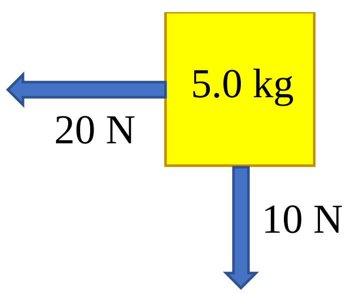
Answer: The net force affecting the object is 14.1 N @ NE. The object will accelerate NE at 2.82 m/s^2.

Illustrative Example 4

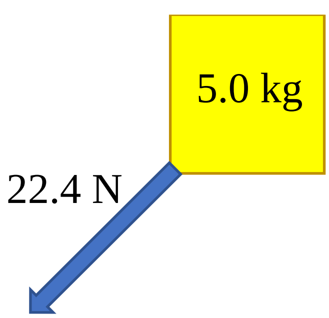
Original free body diagram



Redrawn with leftover forces



Net force



- Step 1: List the forces (there are three forces)
  20 N north; 30 N south
  10 N east; 5 N west, 25 N west

- Step 2: Calculate the net force in the N-S transect (add together the forces in the north and south directions).
  $F_{N-S} = +20N + -30N = -10N =$ **10 N south**
  Leftover force = 10 N north

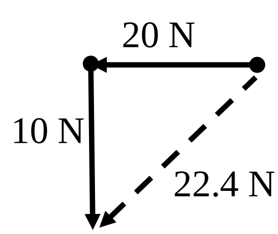
- Step 2: Calculate the net force in the E-W transect (add together the forces in the east and west directions).
  $F_{E-W} = +10N + -5N + -25\,N = 10N =$
  20 N west
  Leftover force = 20 N west

- Step 3: Redraw the free body diagram using only the leftover forces in the N-S and E-W transects.

- Step 4: Determine the overall net force affecting the object. The leftover forces are 10 N south and 20 N west. They are the sides of the right triangle.

  Use the Pythagorean Theorem to solve for the net force. The net force is the hypotenuse of the right triangle.

$$C = \sqrt{(20N)^2 + (10N)^2} = 22.4\,N\ @\ \text{SW}$$



- Step 5: Calculate the acceleration affecting the object

$$a = \frac{F}{m} = \frac{22.4\,N}{5.0kg} = 4.48\,{}^{m}/{}_{s^2}\ @SW$$

Answer: The net force affecting the object is 22.4 N @ SW. The object will accelerate SW at 4.48 m/s^2.