Physics 221, February 1

Applications of Newton's laws of motion

Key Concepts:

- Projectile motion
- Hooke's law
- Friction
- Uniform circular motion

Electronic Devices

Please separate your professional from your social life

Do not use social media during class time.

Permit yourself to think and participate.

Forces

On macroscopic scale, the most common forces (interactions) we experience on a daily basis are gravity and contact forces.

Gravity near the surface of Earth:

- proportional to mass
- constant as a function of position
- pointing straight downward

$\mathbf{F}_g = m\mathbf{g}$

constant force → constant acceleration

Projectile motion

Projectile motion is motion of a particle through a region of space where it is subject to **constant acceleration**.

Let the acceleration be along the y-direction and let the trajectory lie in the xy-plane.

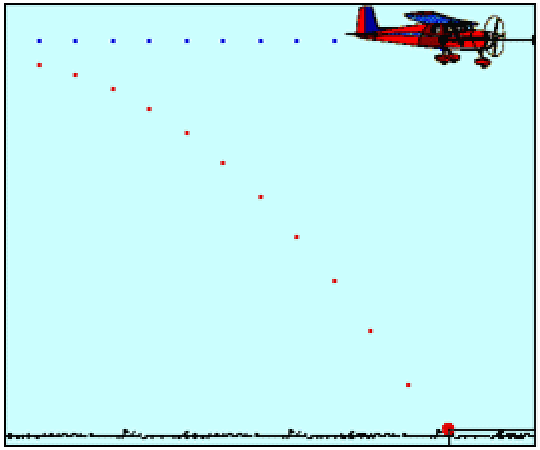
Then $v_x = v_{0x}$, $\Delta x = v_{0x}\,\Delta t$, $v_y = v_{0y} + a_y\Delta t$, $\Delta y = v_{0y}\Delta t + (1/2)a_y\Delta t^2$.

The motion along the x-direction is independent of the motion along the y-direction.

If $a_y = -g$ then

$v_x = v_{0x}$, $\Delta x = v_{0x}\,\Delta t$,

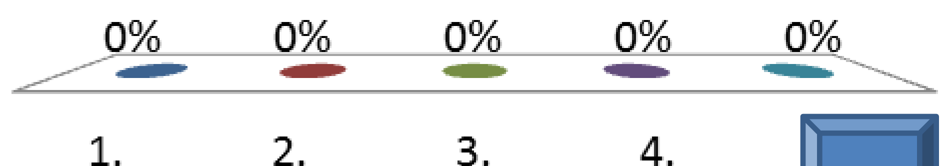
$V_y = v_{0y} - g\Delta t$, $\Delta y = v_{0y}\Delta t - (1/2)g\Delta t^2$.



A ball is dropped from the roof of a 45 m tall building. How long after it has been released does it hit the ground?

Let $g = 10\ m/s^2$.

1. 5 s
2. 9 s
3. 3 s
4. 4.5 s
5. 2.21 s



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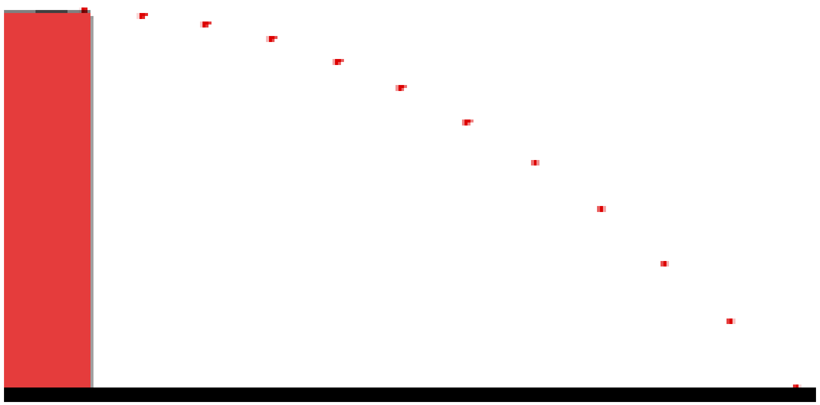
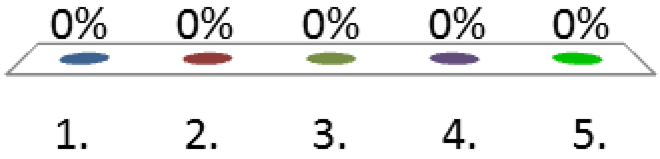
A ball is thrown horizontally from the roof of a 45 m tall building with a speed of 20 m/s. What is its horizontal distance from the building when it strikes the ground?
Let $g = 10\ m/s^2$.



1. 20 m
2. 45 m
3. 90 m
4. 60 m
5. This cannot be determined from the given information.



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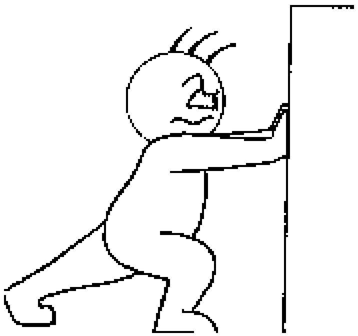
Contact forces

Contact forces are pushes and pulls objects exert on each other because they are in contact with each other and "atoms need their space".



(On a microscopic scale, contact forces are electromagnetic forces and we need quantum mechanics to try to understand them.)

We often describe contact forces using these categories

elastic forces
normal forces
friction
drag

Free-body diagrams

To find the

net force

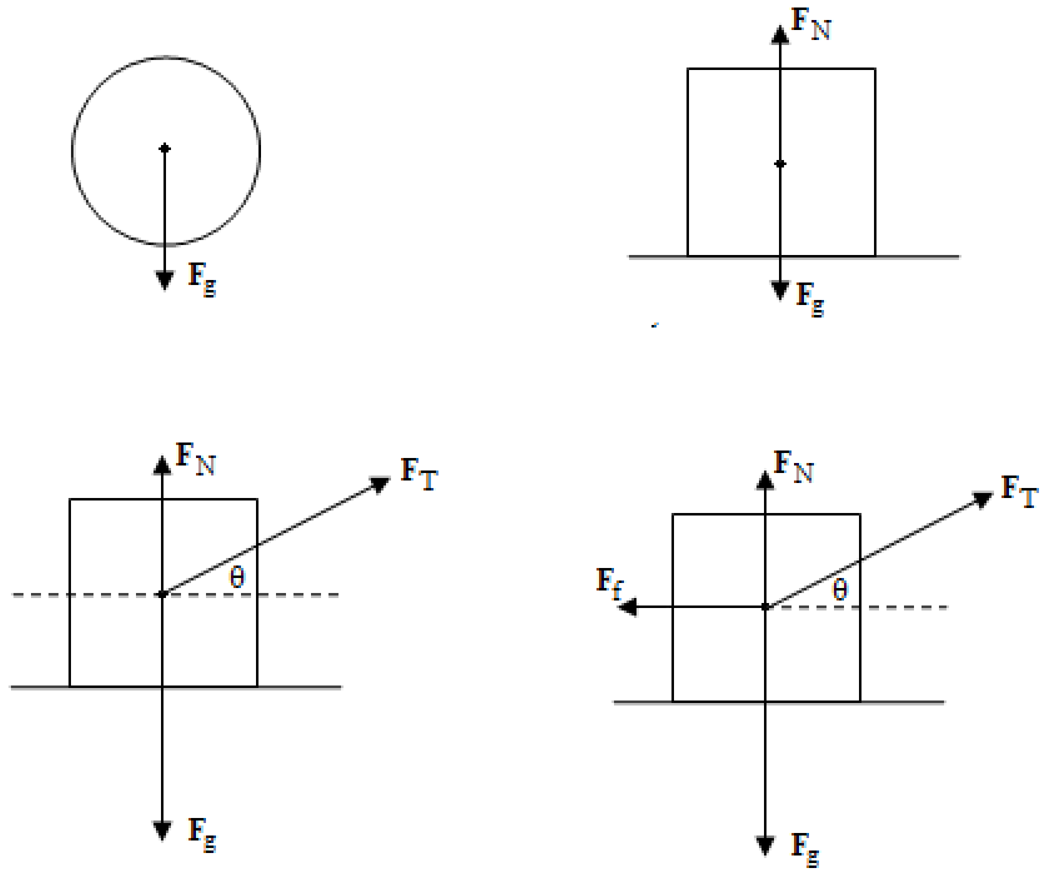
on an object,

add all the
vector forces

that act
on the object.

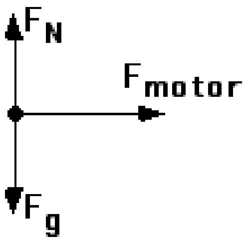
Free-body diagrams

help with this task.

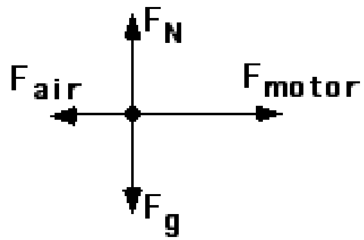


What do these diagrams show?

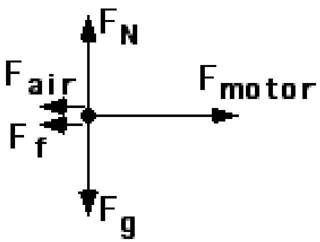
A car accelerates down a straight highway.
Which of the free-body diagrams shown best represents this situation?



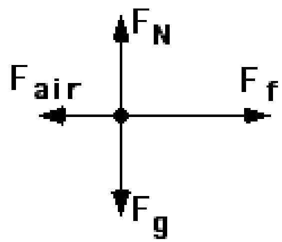
(1)



(2)



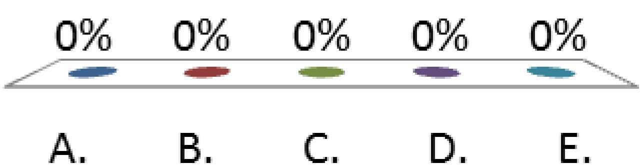
(3)



(4)

(5) None of the above

A. 1
B. 2
C. 3
D. 4
E. 5



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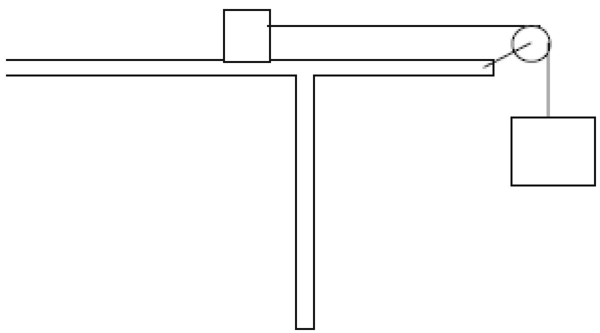
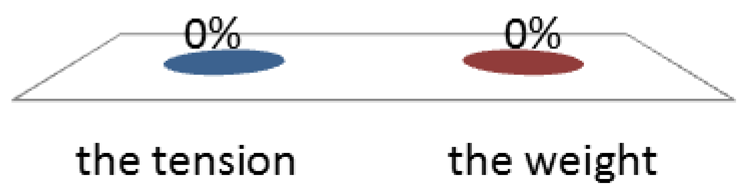
Two blocks, one sitting on a table and the other heavier one hanging over its edge, are connected by a light string as shown in the figure. Which force makes the block on the table move, the tension in the string or the weight of the hanging block?



Hint:
Draw a free body diagram.
Which forces are acting on the small block?

1. the tension
2. the weight



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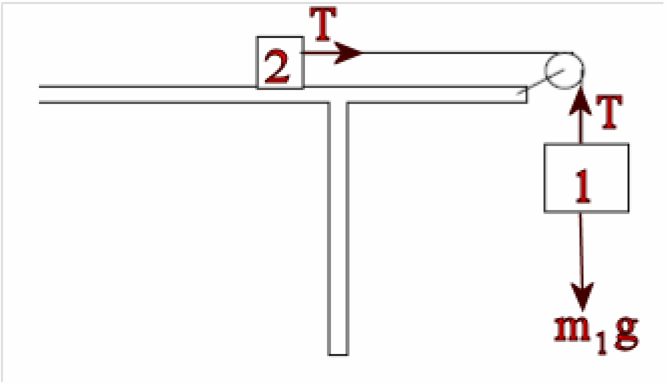
Two blocks, one sitting on a table and the other heavier one hanging over its edge, are connected by a light string as shown in the figure.
What is the acceleration of the blocks?

The blocks accelerate together, the acceleration a is the same for both blocks.

(1) $m_1g - T = m_1a$

(2) $T = m_2a$



Insert (2) into (1).

$m_1g - m_2a = m_1a$

Solve for a.

$a = m_1g/(m_1+m_2)$

Friction

The frictional force always acts between two surfaces, and opposes the **relative motion** of the two surfaces.

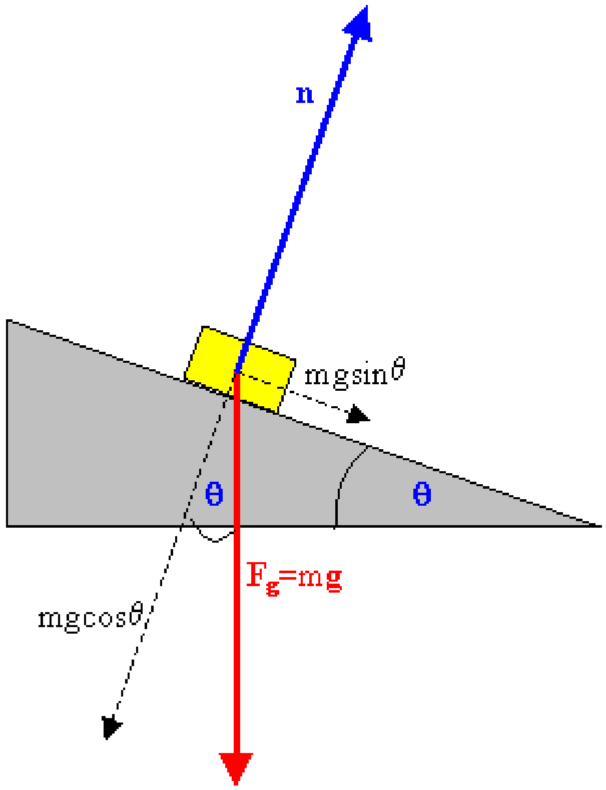
Static friction: $f_s \leq \mu_s N$

Kinetic friction: $f_k = \mu_k N$

N = magnitude of the force pressing the surfaces together

What is the direction of the frictional force on the block if

i) the block is at rest on the ramp?
ii) the block moves up the ramp?
iii) the block is moves down the ramp?



Let us add friction to this diagram.

A horizontal external force of 20 N acts on a 4 kg box that slides across a surface with constant velocity.

What is the coefficient of kinetic friction μ_k between the box and the surface?

(Let $g = 10\ m/s^2$.)

Hint:
constant velocity ←→ no net force

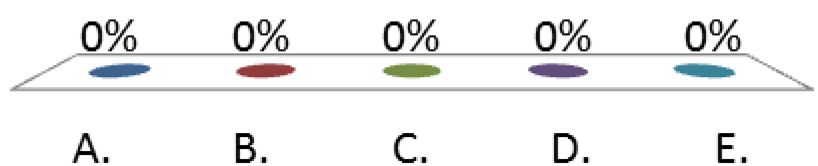
A. 0.25

B. 5

C. 1

D. 0.5

E. 0.1



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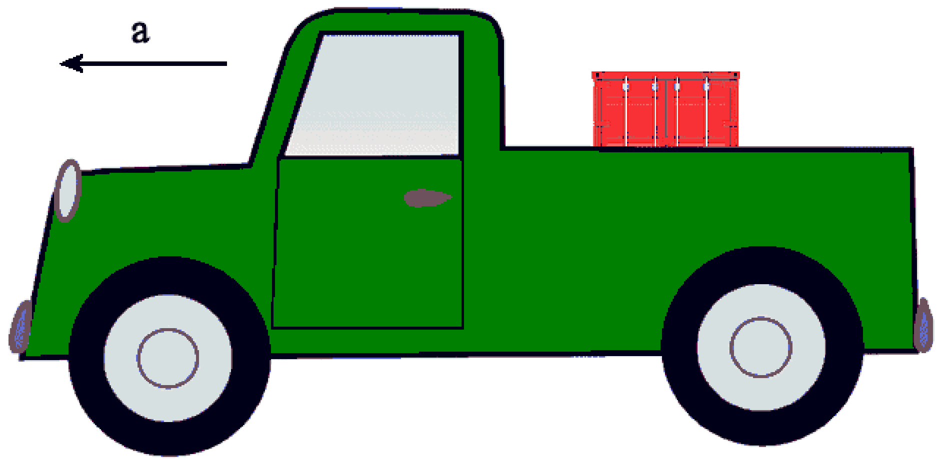
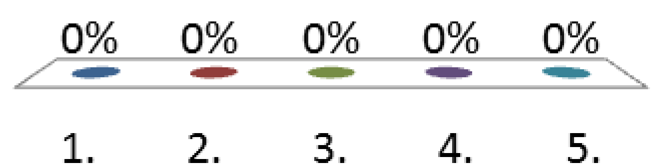
A heavy box sits in the back of a pickup truck. The truck and the box are accelerating towards the left.
What is the direction of the frictional force on the box?



1. Towards the right
2. Towards the left
3. Up
4. Down
5. Down and towards the left



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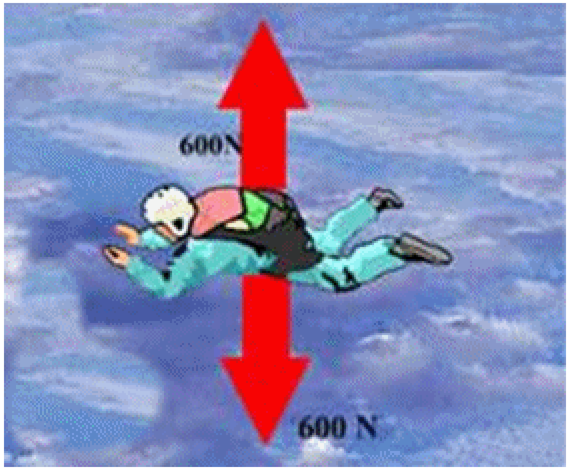
Drag

An object moving through a gas or a liquid is acted on by a resistive force. This force always points in a direction opposite to the direction of the velocity of the object, and its magnitude depends on the speed of the object.

Slow: F_{drag} proportional to v
Fast: F_{drag} proportional to v^2

An object acted on by a constant applied force and a drag force will Eventually reach terminal velocity.



Hooke’s law

No material is perfectly hard. As long as the external pushes or pulls are not too strong, displacement x from equilibrium due to the bending, contraction or expansion is proportional to the magnitude of the pushing or pulling forces.

$$F_{ext} = kx$$

The material pushes back with force

$$F = -kx$$

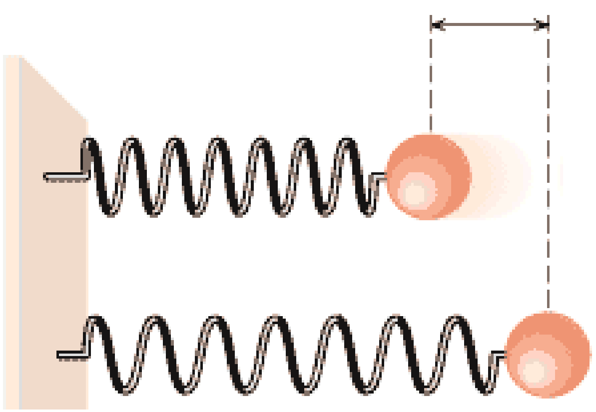
This is Hooke’s law.

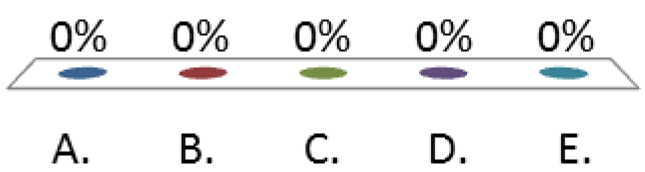
Hooke's law is NOT a law of nature.

It is a rule of thumb that often holds over a limited range of bending, expansion and contraction.

A force of magnitude 10 N compresses an ideal spring by 4 mm. How much force is needed to stretch the same spring by 8 mm?

A. 30 N
B. 15 N
C. 10 N
D. 20 N
E. impossible to know





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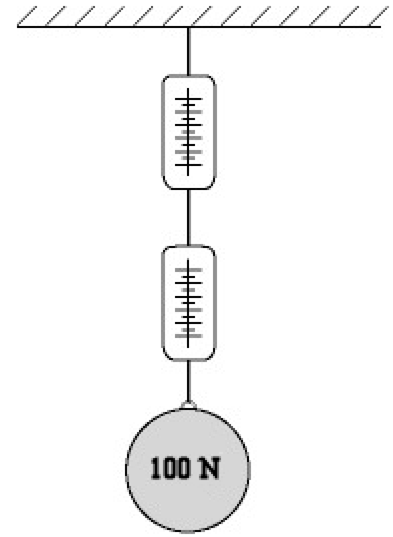
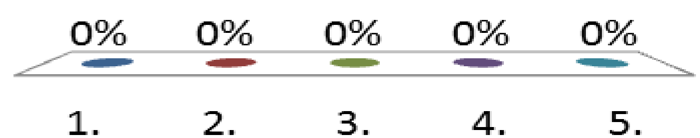
In the figure, a 100 N weight is suspended from two spring scales, each of which has negligible weight. What is the reading of the scales?



1. The top scale will read zero, the lower scale will read 100 N.
2. Each scale will read 100 N.
3. The lower scale will read zero, the top scale will read 100 N.
4. Each scale will read 50 N.
5. Each scale will show a reading between one and 100 N, such that the sum of the two is 100 N. However, exact readings cannot be determined without more information.

Hint: The object stays at rest. The scale reads the force it exerts on the object.



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Circular motion

An object moving in a circle of radius r with speed v is accelerating. This acceleration is called radial acceleration or centripetal acceleration.

This acceleration, $\mathbf{a}_c$, points towards the center of the circle.

The magnitude of the centripetal acceleration vector is

$$a_c = v^2/r.$$

A force is required to make an object move in a circle.

This force is called the centripetal force, with magnitude

$$F_c = m\,v^2/r.$$

$\mathbf{F}_c$ points towards the center of the circle.

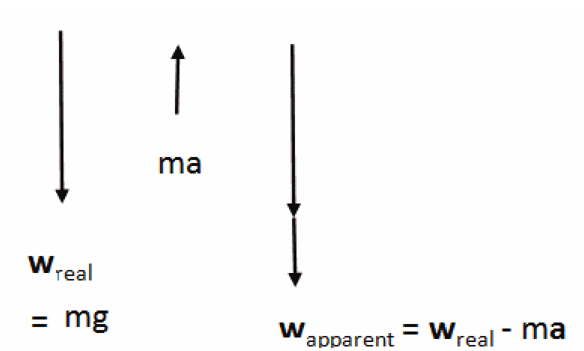
Apparent weight

When you stand on a bathroom scale in an inertial frame, such as this room, its reading is proportional to your real weight.

When you stand on a bathroom scale in an accelerating frame, such as an elevator accelerating upward, its reading is proportional to your apparent weight.

$\mathbf{w}_{apparent} = \mathbf{w}_{real} - m\mathbf{a}$.

For the elevator accelerating upward:



In every accelerating frame we have

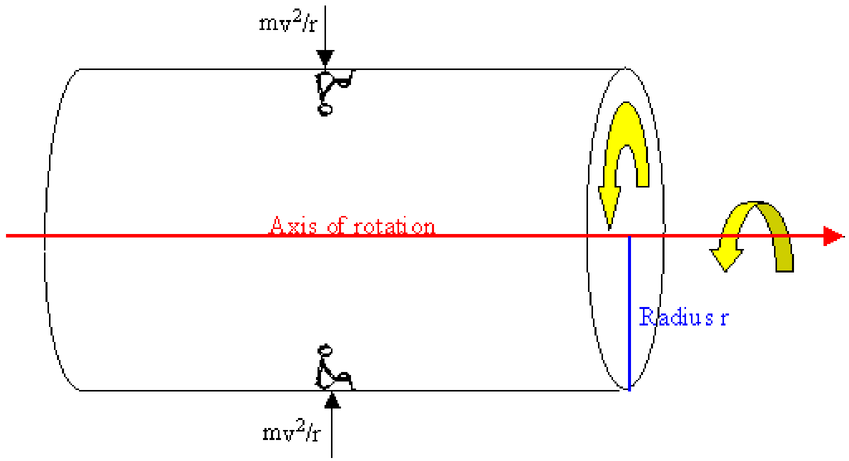
$$\mathbf{w}_{apparent} = \mathbf{w}_{real} - m\mathbf{a}$$

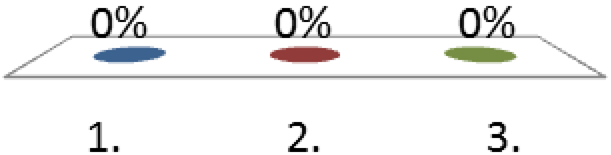
The apparent weight of a mass m is its real weight minus its mass times the acceleration of the frame (vector addition).

In outer space, where $\mathbf{w}_{real} = 0$, $\mathbf{w}_{apparent} = - m\mathbf{a}$

Some engineers have suggested that we can simulate gravity in outer space by having a circular rotating space station where persons feel an outward-directed fictitious force due to the rotation of the station. The reason they feel such a force is because

1. their velocity is toward the center of the space station and their inertia tends to keep them moving outward.
2. they are accelerating toward the center of the space station and the walls of the space station provide the centripetal force, which they experience as an apparent weight.
3. their velocity is away from the center of the space station and their inertia tends to make them move in towards the center.





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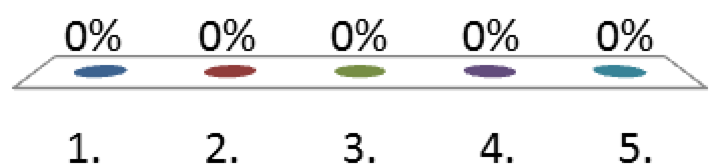
A ring shaped space station with a radius of 2 km is spinning, so that the speed of the rim is 100 m/s. A 50 kg woman sits on the inside of the rim. What is the magnitude of his apparent weight?

1. 5000 N
2. 350 N
3. 250000 N
4. 500 N
5. 250 N



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