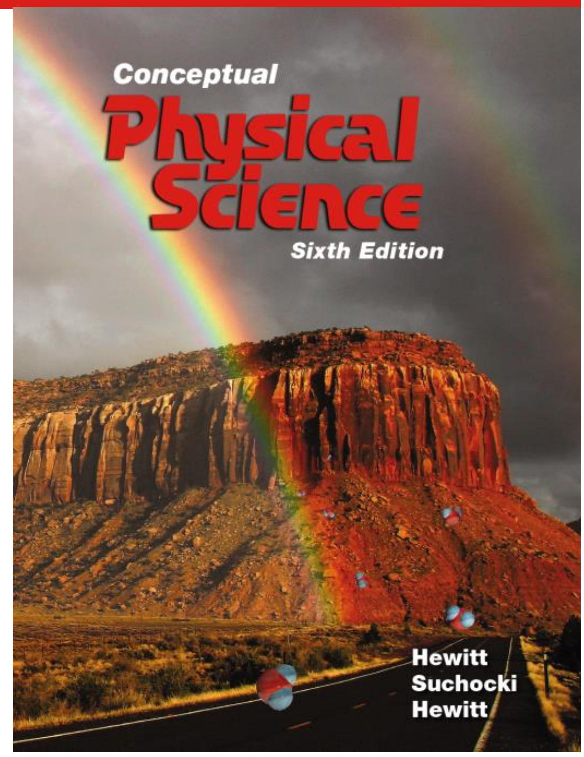
Chapter 1 Lecture

Chapter 1: Patterns of Motion and Equilibrium



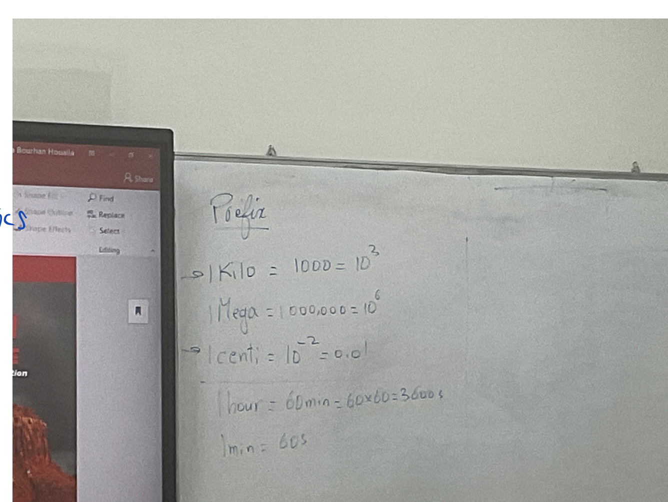
1

- covered
- yet to be covered

This lecture will help you understand:

- Galileo's Concept of Inertia
- Mass—A Measure of Inertia
- Net Force
- The Equilibrium Rule (balance)
- Support Force
- Dynamic Equilibrium
- The Force of Friction
- Speed and Velocity
- Acceleration

kinematics



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Aristotle's assertion (philosophical idea purely imagined NOT tested)
classified motion as:
1) Natural Motion
2) violent Motion

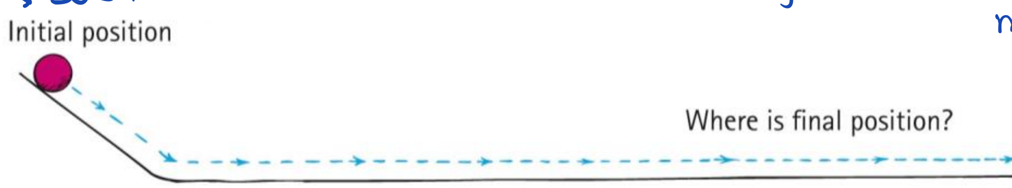
property of matter

Galileo's Concept of Inertia

if its in motion, it will cont to be in motion

- Italian scientist Galileo demolished Aristotle's assertions in early 1500s.
- In the absence of a force, objects once set in motion tend to continue moving indefinitely. (forever)

5Joules → if it lacks friction, the object will constantly move



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Galileo's Concept of Inertia

- Legend of the Leaning Tower of Pisa:
  - Galileo showed that dropped objects fall to the ground at the same time when air resistance is negligible.

independent of mass

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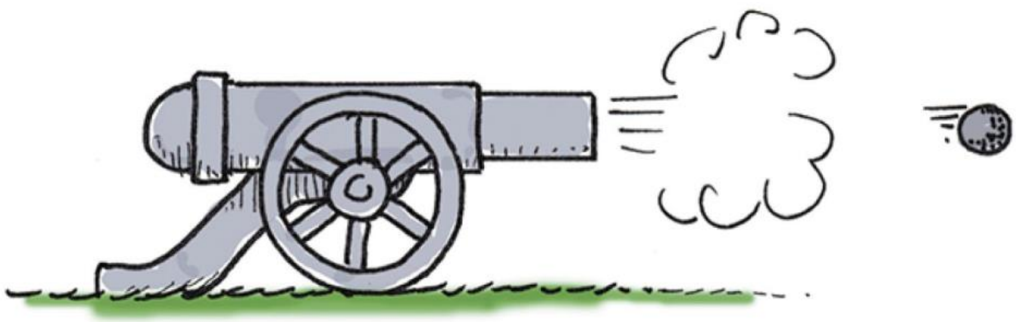
Galileo's Concept of Inertia

- Discovery:
  - In the absence of friction, no force is necessary to keep a horizontally moving object moving.



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Galileo's Concept of Inertia

- Conclusion:
  - The tendency of a moving body to keep moving is natural—every material object resists *change* in its state of motion. This property of things to resist change is called **inertia**.

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Galileo's Concept of Inertia
CHECK YOUR NEIGHBOR

The use of inclined planes for Galileo's experiments helped him to

A. eliminate the acceleration of free fall.

B. discover the concept of energy.

C. discover the property called inertia.

D. discover the concept of momentum.

Galileo's Concept of Inertia
CHECK YOUR ANSWER

The use of inclined planes for Galileo's experiments helped him to

A. eliminate the acceleration of free fall.

B. discover the concept of energy.

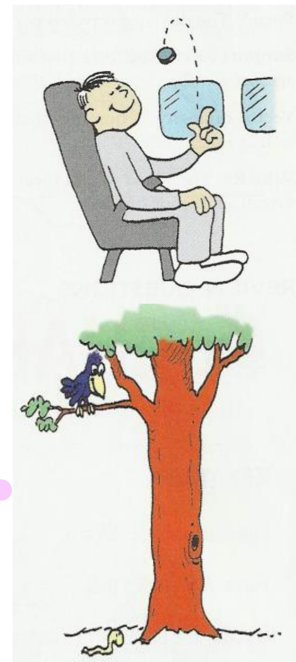
C. discover the property called inertia.

D. discover the concept of momentum.

Explanation:

Note that inertia is a property of matter, not a reason for the behavior of matter.

Inertia: Additional Examples



- When we flip a coin in a high speed car, we catch the moving coin as we would if the car was at rest. This happens because of the coin's inertia and its forward motion at the speed of the car.
- Birds move from the tree branch vertically below and catch the worm. If inertia is neglected this would be impossible and the worm would be swept far away with the moving earth. The actual situation is that when the bird drops from the branch its initial sideways motion remains unchanged. It catches the worm quite unaffected by the motion of its environment.

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Inertia: Additional Examples

- Rapid deceleration is sensed by the driver who is pushed forward when the brakes are applied.
- The downward motion and sudden stop of the hammer hand tightens the hammer hand
- A tablecloth is whipped from beneath dishes sitting on a table, leaving the dishes in their initial state of rest.

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→ depends on amount of matter

Mass—A Measure of Inertia

- The amount of inertia possessed by an object depends on the amount of matter—the amount of material that composes it—its **mass:**

greater mass ⇒ greater inertia

smaller mass ⇒ smaller inertia

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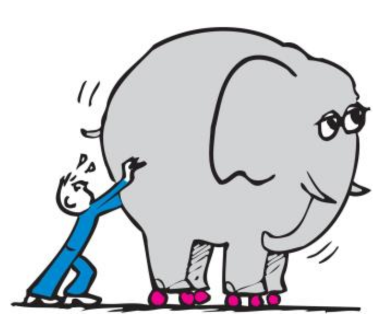
Mass—A Measure of Inertia

- Mass
  - Quantity of matter in an object
  - Measure of inertia or sluggishness that an object exhibits in response to any effort made to start it, stop it, or change its state of motion in any way



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Mass—A Measure of Inertia

- Weight
  - Amount of gravitational pull on an object
  - Proportional to mass

Twice the mass ⇒ twice the weight

Half the mass ⇒ half the weight

Weight = mass × acceleration of gravity

↓ vertically downward

$$w = mg$$

(Newton (N)) → kg → gravitational acceleration = 9.81 m/s² ≈ 10 m/s²

m: mass in kg

g: acceleration of gravity $\cong 10\ \mathrm{m/s^2}$

Weight is a force and has units of Newton (N). **Direction of weight is downwards always.**

$g = 10\frac{m}{s^2}$, $g = 10\frac{N}{kg}$

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A note on units

- Most physical quantities have units. It is necessary to indicate the units used.
- We use the international system of units (**SI-units**). There are **three basic units in mechanics. In SI-units these are**:
  - **Length in meters (m)**
  - **Mass in kilograms (kg)**
  - **Time in seconds (s)**
- Other physical quantities have derived units, for example:
  - Speed in $\mathrm{m/s}$,
  - Acceleration in $\mathrm{m/s^2}$
  - Force in N ($\mathrm{N} \equiv \mathrm{kg.m/s^2}$)
  - Volume in $\mathrm{m^3}$
- One cannot mix different systems of units. **It is recommended to use SI-units.** Carry unit conversion when necessary

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Example (including unit conversion)

- Calculate the weight (→ N) of a 200 gram (→ mass (kg)) object.
  (Hint: check if the units are consistent and make proper unit conversion!)

$m = 200\text{gram} = \frac{200}{1000} = 0.2\,\text{kg}$

$w = m \times g = (0.2)(10) = 2\,\text{N}$

- Calculate the mass of a man who weighs 600 N

$m = \frac{w}{g} = \frac{600\,\text{N}}{10\,\text{m/s}^2} = 60\,\text{kg}$

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mass vs. volume vs. density

Mass—A Measure of Inertia

- Mass versus volume:
  - **Mass** involves how much *matter* an object contains
  - **Volume** involves how much *space* an object occupies
- Density: Measure of compactness
  - **Density** is the measure of how much mass occupies a given space → $\frac{m}{V}$

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Extra Exercise

An apple has a mass of 150g on Earth

a) what is its mass on the moon?

150g → ÷1000 = 0.15 kg
(mass on the moon will be the same as the mass on Earth)

b) what is its weight on earth?

weight = mass × gravity

weight = 0.15 × 10

= 1.5 N

c) what is g on Moon if its weight on the moon is 0.25 N

$$w = m \times g$$

$$\frac{0.25}{0.15} = \frac{0.15}{0.15} \times g$$

$$g = 1.666\ldots$$

$$\approx 1.67\ m/s^2$$

Mass—A Measure of Inertia
CHECK YOUR NEIGHBOR

The concept of inertia mostly involves

A. mass.

B. weight.

C. volume.

D. density.

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Mass—A Measure of Inertia
CHECK YOUR ANSWER

The concept of inertia mostly involves

A. mass.

B. weight.

C. volume.

D. density.

Explanation:

Anybody get this wrong? Check the title of this slide! :-)

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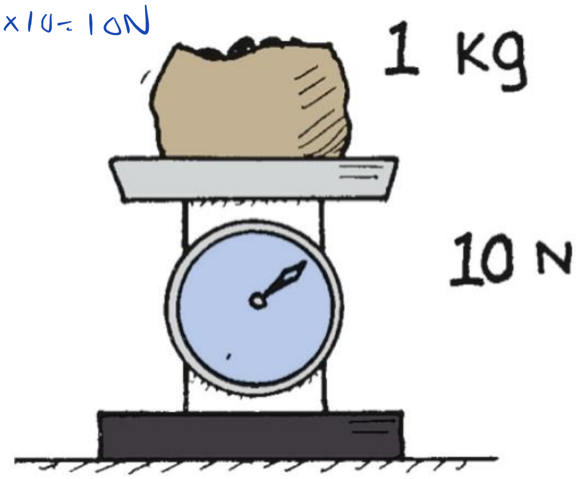
Mass—A Measure of Inertia

- Kilogram
  - **standard unit of measurement for mass**
  - on Earth's surface, 1 kg of material weighs 10 newtons $W = 1 \times 10 = 10N$
  - away from Earth (on the Moon), 1 kg of material weighs less than 10 newtons



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Mass—A Measure of Inertia

Checkpoint

1. Does a 2 kg iron block have twice as much ***inertia*** as a 1 kg iron block? twice as much ***mass***? Twice as much ***volume***? Twice as much ***weight*** when weighed in the same location? yes, more mass = more inertia
2. Does a 2 kg iron block have twice as much ***inertia*** as a 1 kg bunch of bananas? twice as much ***mass***? Twice as much ***volume***? Twice as much ***weight*** when weighed in the same location?
3. Does the ***mass*** of a bar of gold ***vary with location***?

NO

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Mass—A Measure of Inertia
CHECK YOUR NEIGHBOR

The density of 1 kilogram of iron is

A. less on the Moon.
B. the same on the Moon.
C. greater on the Moon.
D. All of the above.

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Mass—A Measure of Inertia
CHECK YOUR ANSWER

The density of 1 kilogram of iron is

A. less on the Moon.
B. the same on the Moon.
C. greater on the Moon.
D. All of the above.

Explanation:

Both mass and volume of 1 kilogram of iron is the same everywhere, so density is the same everywhere.

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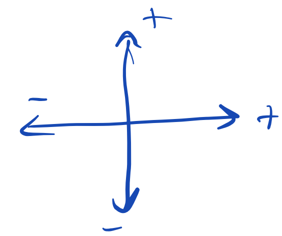
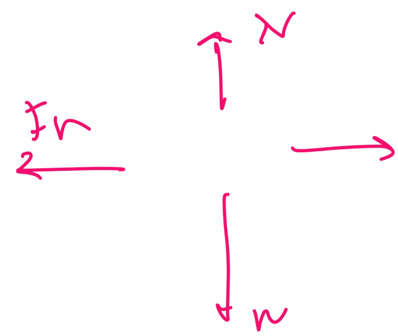
Force → vector quantity (magnitude + direction)

cannot be -ve



- **Force: simply a push or a pull**
  - Results from an interaction between two objects
  - Units of force is Newton (N)
  - Forces are vector quantities: They have direction
- Some common forces:
  1. **Weight**
  2. **Support/Normal force**
  3. **Friction force**

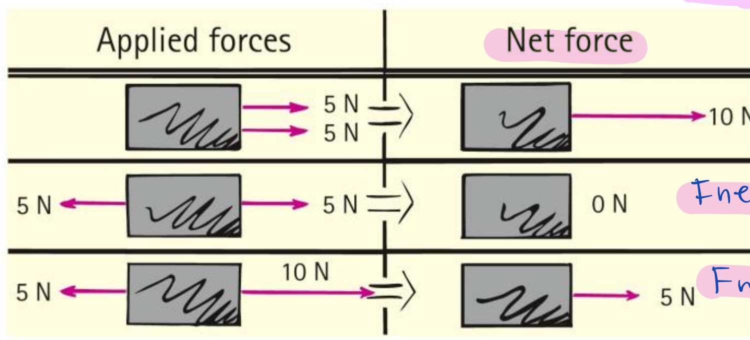


A note on vector and scalar quantities

- Physical quantities are divided into two main types:
  1) Vector Quantities: quantities that have magnitude and direction. (Velocity, acceleration, force, weight, …)
  2) Scalar Quantities: quantities that have magnitudes only. (Time, temperature, mass, speed, work, energy, power…)

Net Force

- Net force
  - combination of all forces that act on an object
  - changes an object's motion



$F_{net} = +5 + 5 = 10\,N$ — mag: 10N, di: right

$F_{net} = -5 - 5 = 0\,N$

$F_{net} = +10 - 5 = 5\,N$ — mag: 5N, di: right

* F_{net}, F_{total}, $\sum \vec{F}$ → sum of forces

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Net Force
CHECK YOUR NEIGHBOR

A cart is pushed to the right with a force of 15 N while being pulled to the left with a force of 20 N. The net force on the cart is

A. 5 N to the left.

B. 5 N to the right.

C. 25 N to the left.

D. 25 N to the right.

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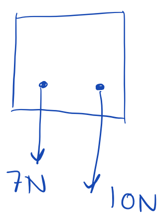
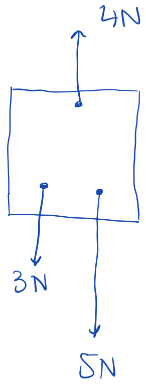
Extra Drill (Net Forces)

Find Fnet



$F_{net} = -10 - 7 = -17N$

- magnitude: 17N
- direction: downwards

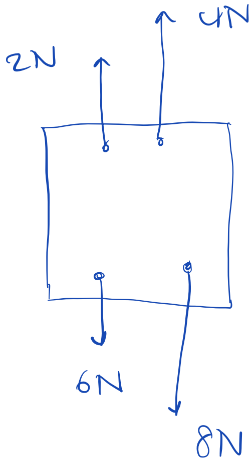


$F_{net} = -3 - 5 + 4$

$= -8 + 4$

$F_{net} = -4N$

- magnitude: 4N
- direction: downwards



$F_{net} = -6 - 8 + 2 + 4$

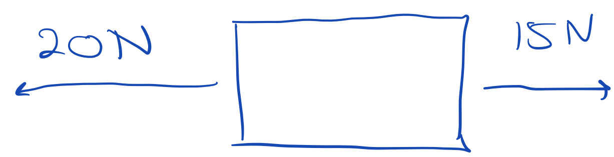
$F_{net} = -8N$

- magnitude: 8N
- direction: downwards

Net Force
CHECK YOUR ANSWER

A cart is pushed to the right with a force of 15 N while being pulled to the left with a force of 20 N. The net force on the cart is

A. 5 N to the left.
B. 5 N to the right.
C. 25 N to the left.
D. 25 N to the right.



$-20N + 15N = -5N$

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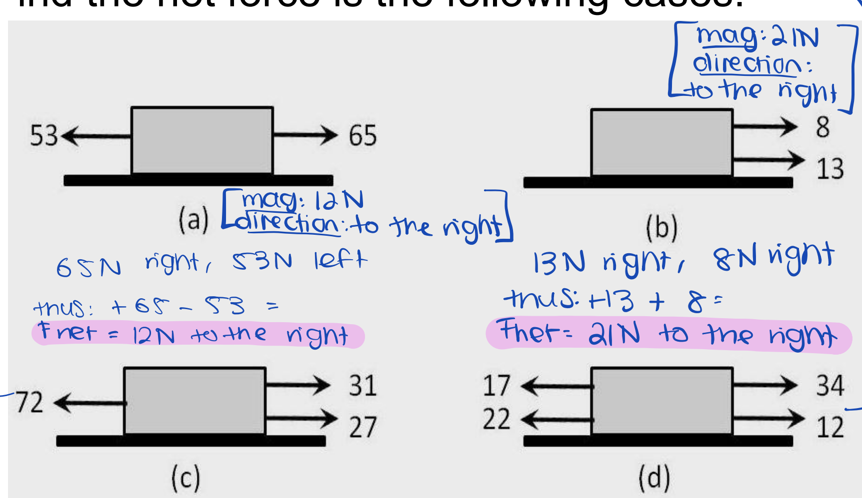
a) magnitude = 14 N, direction = to the left

Example

31N right, 27N right, 72N left
Fnet = +31 + 27 − 72 = 14N

34N right, 12N right, 17N left, 22N left
Fnet = +34 + 12 − 17 − 22 = 7N
m: 7N
d: to the right

- Find the net force is the following cases:



a) 12 N (right), b) 21 N (right), c) 14 N (left), d) 7 N (right)

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The Equilibrium Rule

- The **equilibrium rule:**

  The vector sum of forces acting on a non-accelerating object or system of objects equals zero.

  Mathematical notation: $\Sigma F = 0$.

• $\Sigma \bar{F} = 0$ $F_{net} = 0$ (forces from all directions cancel each other)

Static Equilibrium
at rest
(not moving)

Dynamic Equilibrium
velocity (speed + direction) is constant (not changing)
(is the same)

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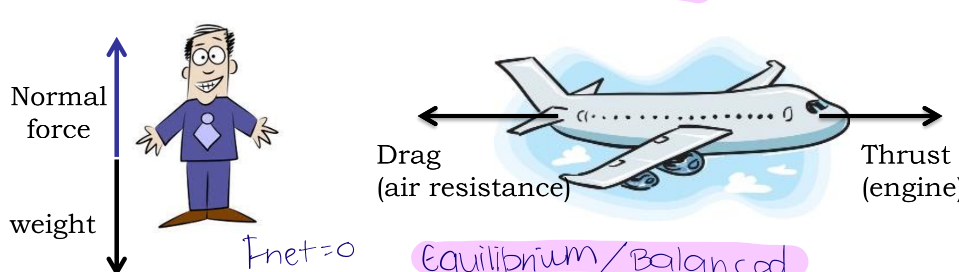
Types of Equilibrium

1. **Static equilibrium**: objects at rest (stationary objects)
2. **Dynamic equilibrium**: objects moving at a constant velocity

(***constant velocity = constant speed in a straight line***).

When two or more forces cancel to zero on a moving object, then the object is in equilibrium.



$F_{net} = 0$
$\Sigma \bar{F} = 0$
$F_{total} = 0$

Equilibrium / Balanced

static
at rest

dynamic
moving with constant velocity (same speed & same direction)

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constant speed + same direction

The Equilibrium Rule
CHECK YOUR NEIGHBOR

The equilibrium rule, $\Sigma F = 0$, applies to

A. vector quantities.
B. scalar quantities.
C. Both of the above.
D. Neither of the above.

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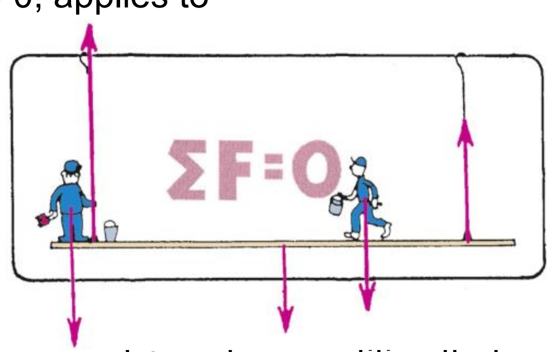
The Equilibrium Rule
CHECK YOUR ANSWER

The equilibrium rule, $\Sigma F = 0$, applies to

A. vector quantities.
B. scalar quantities.
C. Both of the above.
D. Neither of the above.



Explanation:

Vector addition takes into account + and – quantities that can cancel to zero. Two forces (vectors) can add to zero, but there is no way that two masses (scalars) can add to zero.

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Dynamic Equilibrium
CHECK YOUR NEIGHBOR

A bowling ball is in equilibrium when it

A. is at rest.

B. moves steadily in a straight-line path.

C. Both of the above.

D. None of the above.

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Dynamic Equilibrium
CHECK YOUR ANSWER

A bowling ball is in equilibrium when it

A. is at rest.

B. moves steadily in a straight-line path.

C. Both of the above.

D. None of the above.

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Weight

- Weight is the force due to gravity.
  - measured in Newton (SI-unit is N)
  - always **points downwards** (towards the center of the Earth)

- Recall: $\boldsymbol{w} = \boldsymbol{mg}$

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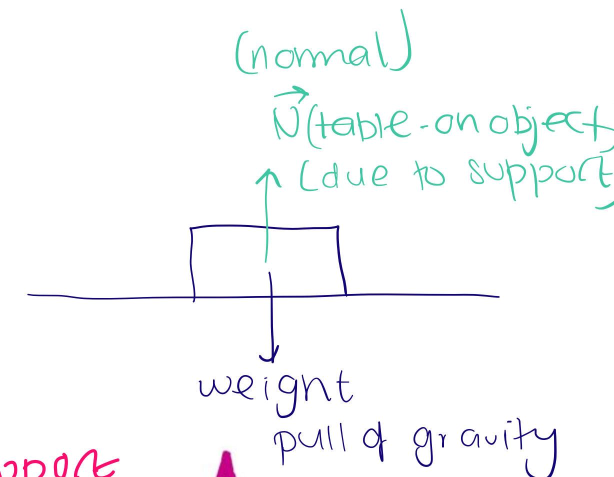
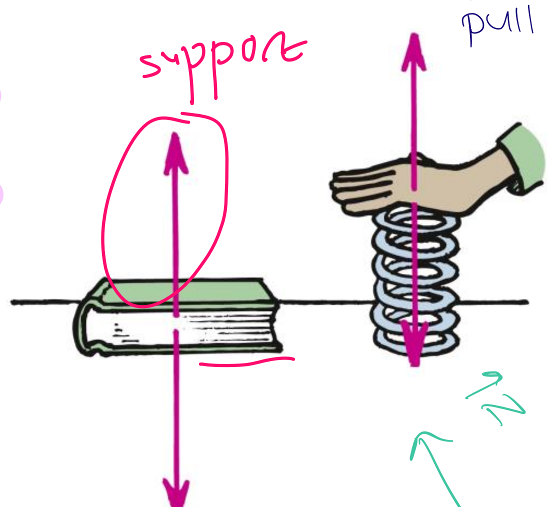
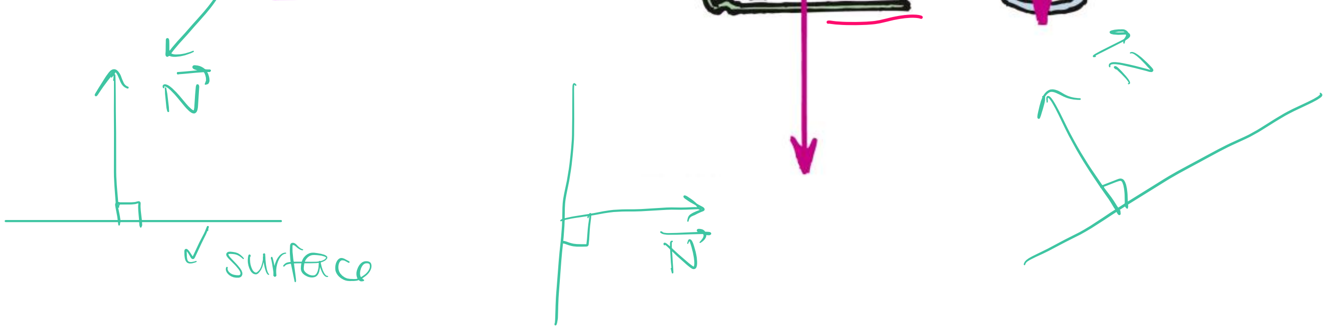


Support Force

- **Support force**
  - is force that supports an object on the surface against gravity
  - is also normal force (perpendicular to the surface)





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Support Force
CHECK YOUR NEIGHBOR

When you stand on two bathroom scales, with one foot on each scale and weight evenly distributed, each scale will read

A. your weight.

B. half your weight.

C. zero.

D. actually more than your weight.

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Support Force
CHECK YOUR ANSWER

When you stand on two bathroom scales, with one foot on each scale and weight evenly distributed, each scale will read

A. your weight.

B. half your weight.

C. zero.

D. actually more than your weight.

Explanation:

You are at rest on the scales, so $\Sigma F = 0$. The sum of the two upward support forces is equal to your weight.

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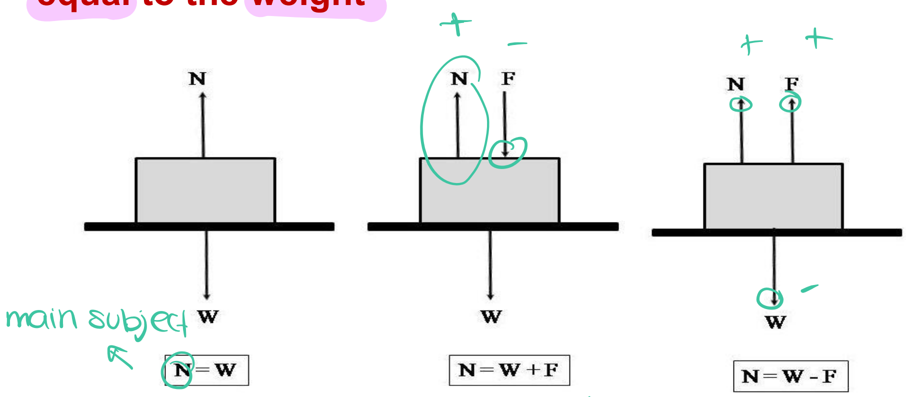
Support Force

since all cases are balanced Fnet = 0

- Note: the support (normal) force is **NOT necessarily equal to the weight**

Fnet = N − F − W

N = F + W



Fnet = 0

0 = +N − W

N = W

Fnet = +N − F − W

Fnet = 0

0 = +N − F − W

N = W + F

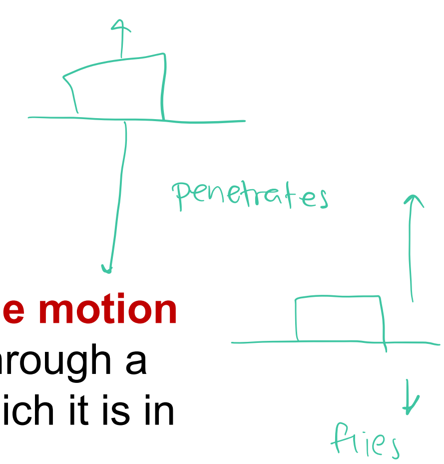
Fnet = +N + F − W

0 = +N + F − W

N = W − F

The Force of Friction

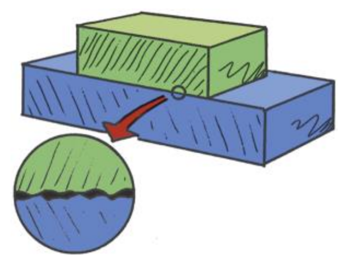
- **Friction**
  - the resistive force that **opposes the motion** or attempted motion of an object through a fluid or past another object with which it is in contact
  - always acts in a direction to oppose motion



Force 5N, Friction 5N (didn't move)

The Force of Friction

- Friction (continued)
  - between two surfaces, the amount depends on the kinds of material and how much they are pressed together
  - due to surface bumps and also to the stickiness of atoms on the surfaces of the two materials



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The Force of Friction
CHECK YOUR NEIGHBOR

The force of friction can occur

A. with sliding objects.

B. in water.

C. in air. (air resistance)

D. All of the above.

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The Force of Friction
CHECK YOUR ANSWER

The force of friction can occur

A. with sliding objects.

B. in water.

C. in air.

D. All of the above.

Explanation:

Friction can also occur for objects at rest. If you push horizontally on your book and it doesn't move, then friction between the book and the table is equal and opposite to your push.

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Mass—A Measure of Inertia

CHECKPOINT

1. Suppose you exert a 50-N horizontal force on a heavy desk resting motionless on your classroom floor. The fact that it remains at rest indicates that 50 N isn't great enough to make it slide. How does the force of friction between the desk and floor compare with your push?
2. You push harder—say, 55 N—and the desk still doesn't slide. How much friction acts on it?
3. You push still harder and the desk moves. Once it is in motion, you push with 60 N, which is just sufficient to keep it sliding at constant velocity. How much friction acts on the desk?
4. What net force does a sliding desk experience when you exert a force of 65 N and friction between the desk and the floor is 60 N?

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Mass—A Measure of Inertia

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1. Suppose you exert a 50-N horizontal force on a heavy desk resting motionless on your classroom floor. The fact that it remains at rest indicates that 50 N isn't great enough to make it slide. How does the force of friction between the desk and floor compare with your push?
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3. You push still harder and the desk moves. Once it is in motion, you push with 60 N, which is just sufficient to keep it sliding at constant velocity. How much friction acts on the desk?
4. What net force does a sliding desk experience when you exert a force of 65 N and friction between the desk and the floor is 60 N?

Were these your answers?

1. The force of friction is 50 N in the opposite direction. Friction opposes the motion that would occur otherwise. The fact that the desk is at rest is evidence that $\Sigma F = 0$.
2. Friction increases to 55 N, and again $\Sigma F = 0$.
3. The force of friction is 60 N, because when the desk is moving at constant velocity, $\Sigma F = 0$.
4. The net force is 5 N, because $\Sigma F = 65\text{ N} - 60\text{ N}$. In this case the desk picks up speed. As we will see, it *accelerates*.

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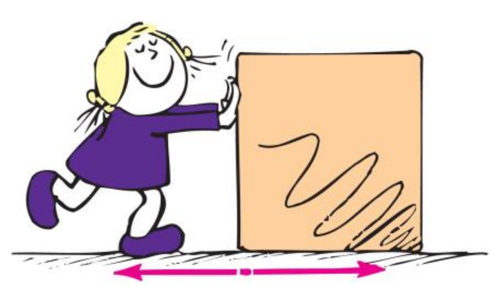
The Force of Friction
CHECK YOUR NEIGHBOR

When Nellie pushes a crate across a factory floor at constant speed, the force of friction between the crate and the floor is

A. less than Nellie's push.
B. equal to Nellie's push.
C. equal and opposite to Nellie's push.
D. more than Nellie's push.



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The Force of Friction
CHECK YOUR ANSWER

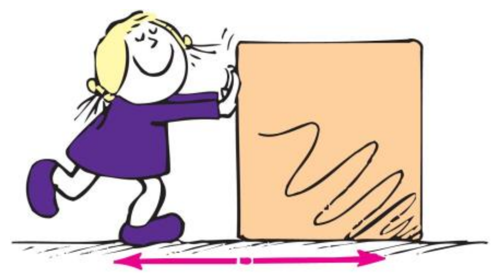
When Nellie pushes a crate across a factory floor at constant speed, the force of friction between the crate and the floor is

A. less than Nellie's push.

B. equal to Nellie's push.

C. equal and opposite to Nellie's push.

D. more than Nellie's push.



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The Force of Friction
CHECK YOUR NEIGHBOR

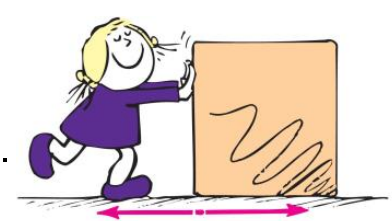
When Nellie pushes a crate across a factory floor at an *increasing speed*, the amount of friction between the crate and the floor is

A. less than Nellie's push.

B. equal to Nellie's push.

C. equal and opposite to Nellie's push.

D. more than Nellie's push.



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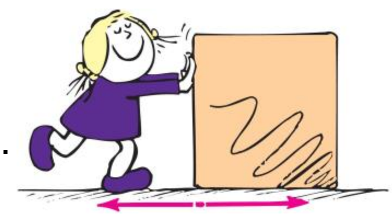
The Force of Friction
CHECK YOUR ANSWER

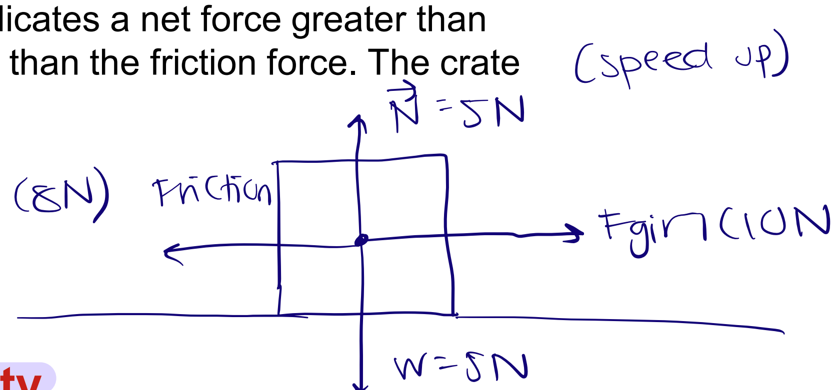
When Nellie pushes a crate across a factory floor at an *increasing speed*, the amount of friction between the crate and the floor is



A. less than Nellie's push.
B. equal to Nellie's push.
C. equal and opposite to Nellie's push.
D. more than Nellie's push.

Explanation:

The increasing speed indicates a net force greater than zero. Her push is greater than the friction force. The crate is not in equilibrium.



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Speed and Velocity

- **Speed** is described as the distance covered per amount of travel time

speed is measured in units of m/s or km/h
Unit conversion:

- $1\ \text{km/h} = \frac{1000\ \text{m}}{60\times 60\ \text{s}} = \frac{5}{18}\text{m/s}$
- $1\ \text{m/s} = \frac{18}{5}\text{km/h}$

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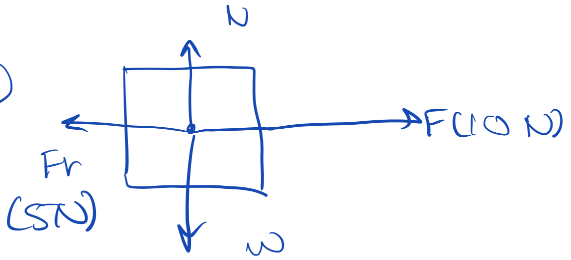
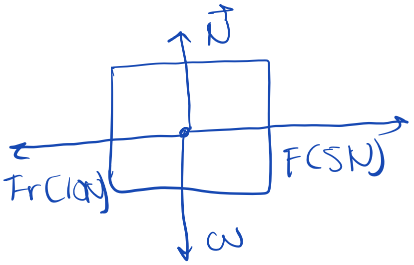
1)



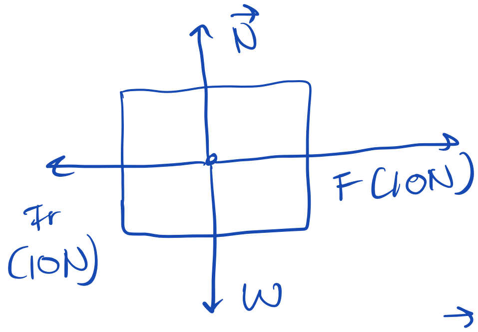
F > Fr → speed up

2)



F > Fr → slow down

3)



F = Fr

Fnet = 0

→ constant velocity

speed

direction

1 km/h = 1000 m / 3600 s = 1/3.6 m/s

To convert km/h → m/s use ÷ by 3.6

To convert m/s → km/h use × by 3.6

1km = 1000m
1min = 60s
1h = 60min
1h = 60×60s
1h = 3600s

Speed and Velocity

- Average speed
  - is total distance traveled divided by travel time
  - equation:

$$\text{average speed} = \frac{\text{total distance covered}}{\text{travel time}}$$

- Instantaneous speed
  - is speed at any instant of time; the speedometer of your car shows the instantaneous speed not the average speed

Speed: scalar (magnitude)

velocity: vector (magnitude + direction)

speed = distance / time → $s = \frac{d}{t}$ (d → m, t → s, s → m/s)

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Speed and Velocity
CHECK YOUR NEIGHBOR

The average speed in driving 30 km in 1 hour is the same average speed as driving

×2 ×2 60

A. 30 km in one-half hour. ×
B. 30 km in two hours.
C. 60 km in one-half hour.
D. 60 km in two hours. ✓

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Speed and Velocity
CHECK YOUR ANSWER

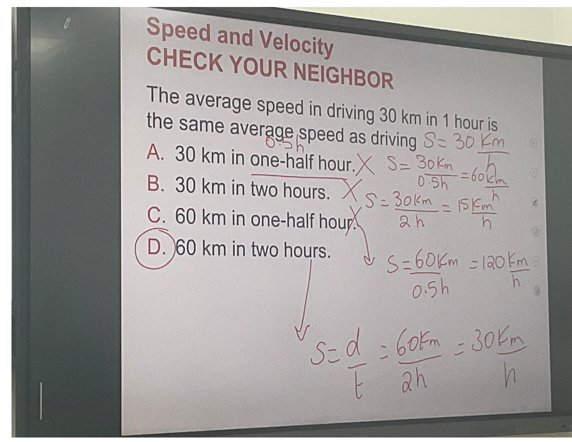
The average speed in driving 30 km in 1 hour is the same average speed as driving

A. 30 km in one-half hour.

B. 30 km in two hours.

C. 60 km in one-half hour.

D. 60 km in two hours.



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Exercises

- A car is moving with a speed of 90 km/h, what is its speed in m/s

$90 \frac{km}{h} \rightarrow \frac{m}{s}$ (×1000)

$90 \frac{km}{h} \div 3.6 = 25 \ m/s$

$90 \times 1000 \rightarrow 90000 \ m / 3600 = 25$

- A horse is running with a speed of 15 m/s what is its speed in km/h

$15 \frac{m}{s} \rightarrow \frac{km}{h}$ (÷0.001)

$15 \frac{m}{s} \times 3.6 = 54 \ km/h$

$15 \frac{m}{s} \div \frac{1000}{1} \frac{km}{s} = 0.015 \frac{km}{s}$

54

$0.015 \frac{km}{s} \times 3600 \frac{s}{h}$

... sec per hr

= 54 km/h

Exercises

0.5 h × 60 sec × 60 sec = 1800 s

- A man runs at 8 m/s; find the distance he travels in half an hour.

$s = \frac{d}{t} \rightarrow 8\ m/s = \frac{d}{t} \rightarrow \frac{8\ m/s}{1} = \frac{d}{1800\ s}$

8 m/s × 1800 s = 14,400 m

- A boy swims at 3 m/s (→ speed), what time is needed for him to travel a distance of 105 m (→ distance)?

$\underset{(m/s)}{speed} = \frac{distance\ (m)}{time\ (s)}$

$\frac{3\ m/s}{1} = \frac{105\ m}{time\ (s)}$

55 $\frac{3s}{3} = \frac{105}{3} \rightarrow s = 35$

Velocity

- When we know both the speed and the direction of motion of an object, then we know its **velocity**.

mag + direction = vector qty

Velocity = speed and direction

- For example, if a car is moving at 80 km/h to the west, then its speed is 80 km/h and its direction is to the west.
- **Constant velocity:** means that the object is neither speeding up nor slowing down and at the same time is moving in the same direction (along a straight line).

No, because the direction is changing

- **Question**: Can you round a curve with your car at constant velocity? Explain. → could be constant speed but the direction is prone to change thus it is not a constant velocity

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calculate the speed in $\frac{m}{s}$ & $\frac{km}{h}$ of an object that covers 1200 km in 45 minutes

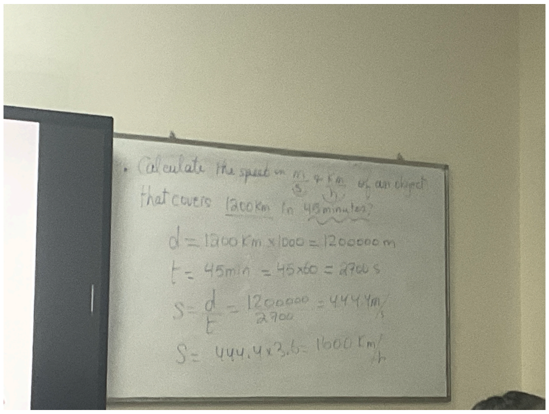
1) speed in $\frac{km}{h}$ = $\frac{1200}{\frac{45 min}{60}}$ = $\frac{1200 km}{0.75 h}$

= $\frac{1200 km}{0.75 h}$ = 1600 km/h

2) speed in $\frac{m}{s}$ → $\frac{km}{h} \div 3.6$

= $1600 \frac{km}{h} \div 3.6$

= 444.44 m/s



distance = 350m

speed = $70 \frac{km}{h}$

time = ? s & h

in seconds

$70 \frac{km}{h} =$

÷3.6

$19.4\,m/s = \frac{350\,m}{s}$

$$\frac{19.4s}{19.4} = \frac{350}{19.4}$$

s = 18.04s

÷3600

h = 0.005h

Find the distance covered by an object if its speed is 80 $\frac{m}{s}$ and the time of travel in is 0.16h?

- speed = 80 $\frac{m}{s}$
- distance = ?
- time = 0.16h

0.16h → ?? s

×3600

576s

$$\text{speed} = \frac{\text{distance}}{\text{time}} \rightarrow 80\,m/s = \frac{d}{576\,s}$$

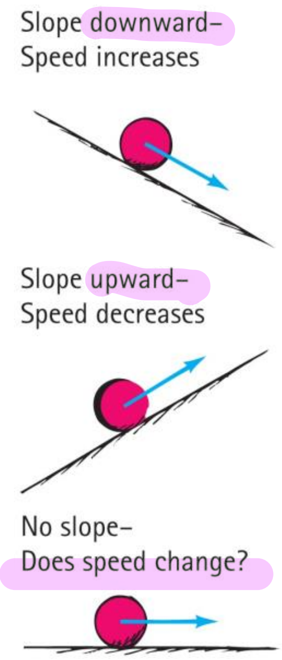
$$\rightarrow \frac{80}{1} = \frac{d}{576}$$

$d = 46{,}080\,m$

represented by delta
↑
change in velocity
⇒ $\Delta v = v_f - v_i$, $\Delta t = t_f - t_i$, $\Delta T = T_f - T_i$, $\Delta x = x_f - x_i$

Acceleration

- Galileo first formulated the concept of acceleration in his experiments with inclined planes.



↓ change in velocity per time

$a = \frac{\Delta v}{t} = \frac{v_f - v_i}{t}$ ↗ $\frac{m}{s}$ ↘ s

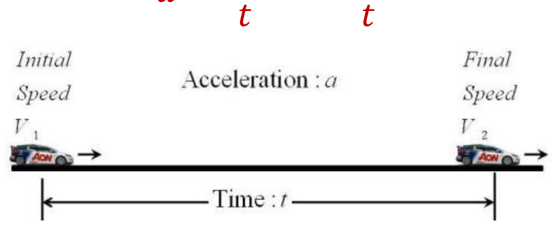
↓ $\frac{m/s}{s} = \frac{m}{s^2}$

Acceleration

- **Acceleration** is the rate at which velocity changes with time. The change in velocity may be in magnitude, in direction, or both.
  - Equation for acceleration:

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{time interval}}$$

$$a = \frac{\Delta v}{t} = \frac{v_f - v_i}{t}$$



rate of → / t

Acceleration
CHECK YOUR NEIGHBOR

e.g. rate of velocity = v / t

An automobile cannot maintain a constant velocity when

A. accelerating.

B. rounding a curve.

C. Both of the above.

D. None of the above.

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Acceleration
CHECK YOUR ANSWER

An automobile cannot maintain a constant velocity when

A. accelerating.

B. rounding a curve.

C. Both of the above.

D. None of the above.

Explanation:

When rounding a curve, the automobile is accelerating, for it is changing direction.

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Acceleration
CHECK YOUR NEIGHBOR

Acceleration and velocity are actually

A. much the same as each other.

B. rates, but for different quantities.

C. the same when direction is not a factor.

D. the same for free-fall situations.

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Acceleration
CHECK YOUR ANSWER

Acceleration and velocity are actually

A. much the same as each other.

B. rates, but for different quantities.

C. the same when direction is not a factor.

D. the same for free-fall situations.

Explanation:

Velocity is the rate at which distance changes with time; acceleration is the rate at which velocity changes with time.

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Notes on Acceleration

constant velocity → 0 velocity

- Notes
  - Constant velocity means no acceleration (= zero acceleration).
  - Unit of acceleration is (units of velocity)/(units of time) = m/s^2.
  - Acceleration is the change in velocity not the change in speed, so even the change in direction only is considered to be acceleration. For example, when a car makes a turn at a constant speed it is still accelerating. +ve direction
  - **Positive acceleration (with positive velocity) means increasing speed (speeding up) and negative acceleration (with positive velocity) means decreasing speed (slowing down).** +ve direction
  - When something slows down, we often call this deceleration.
  - Constant acceleration means that the same increase in velocity takes place in equal time intervals.

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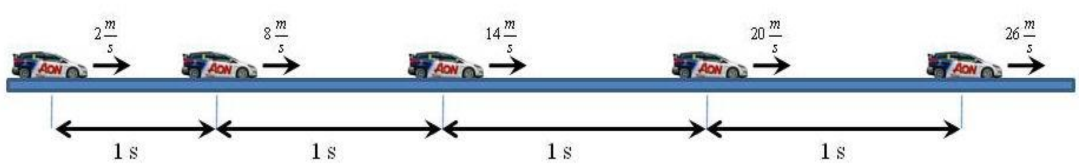
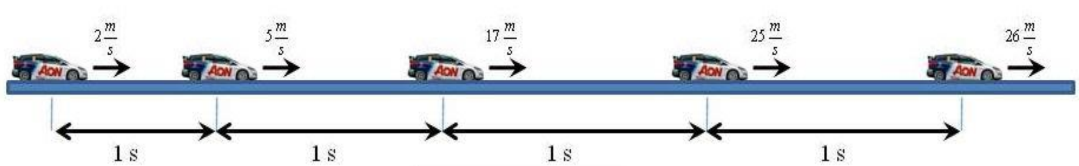
Constant acceleration

- Constant acceleration: constant change in velocity at similar time intervals



Constant acceleration



Variable acceleration

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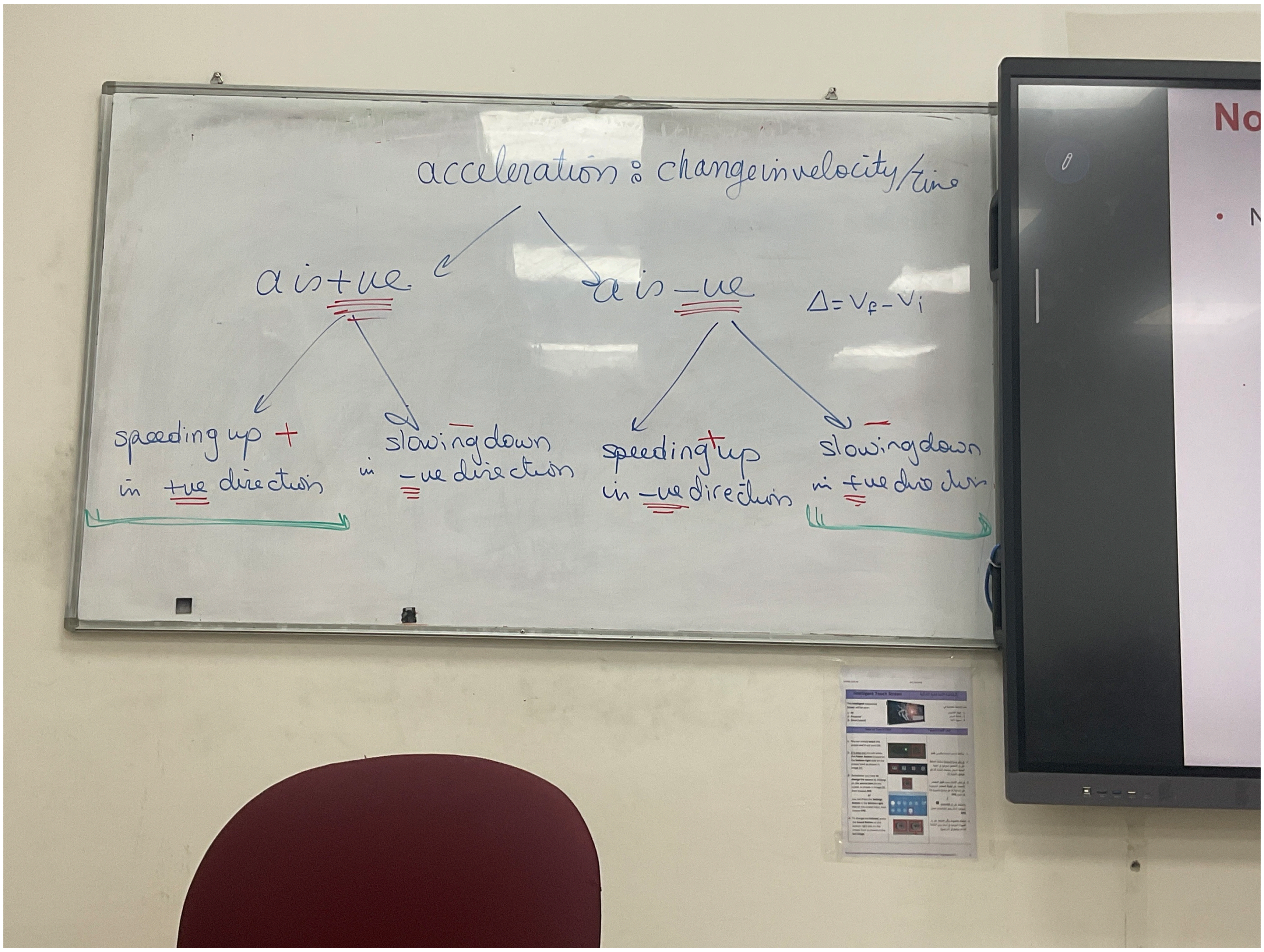
↑ m/s^2

$$a = \frac{\Delta v}{t} = \frac{v_f - v_i}{t}$$ → m/s, → s

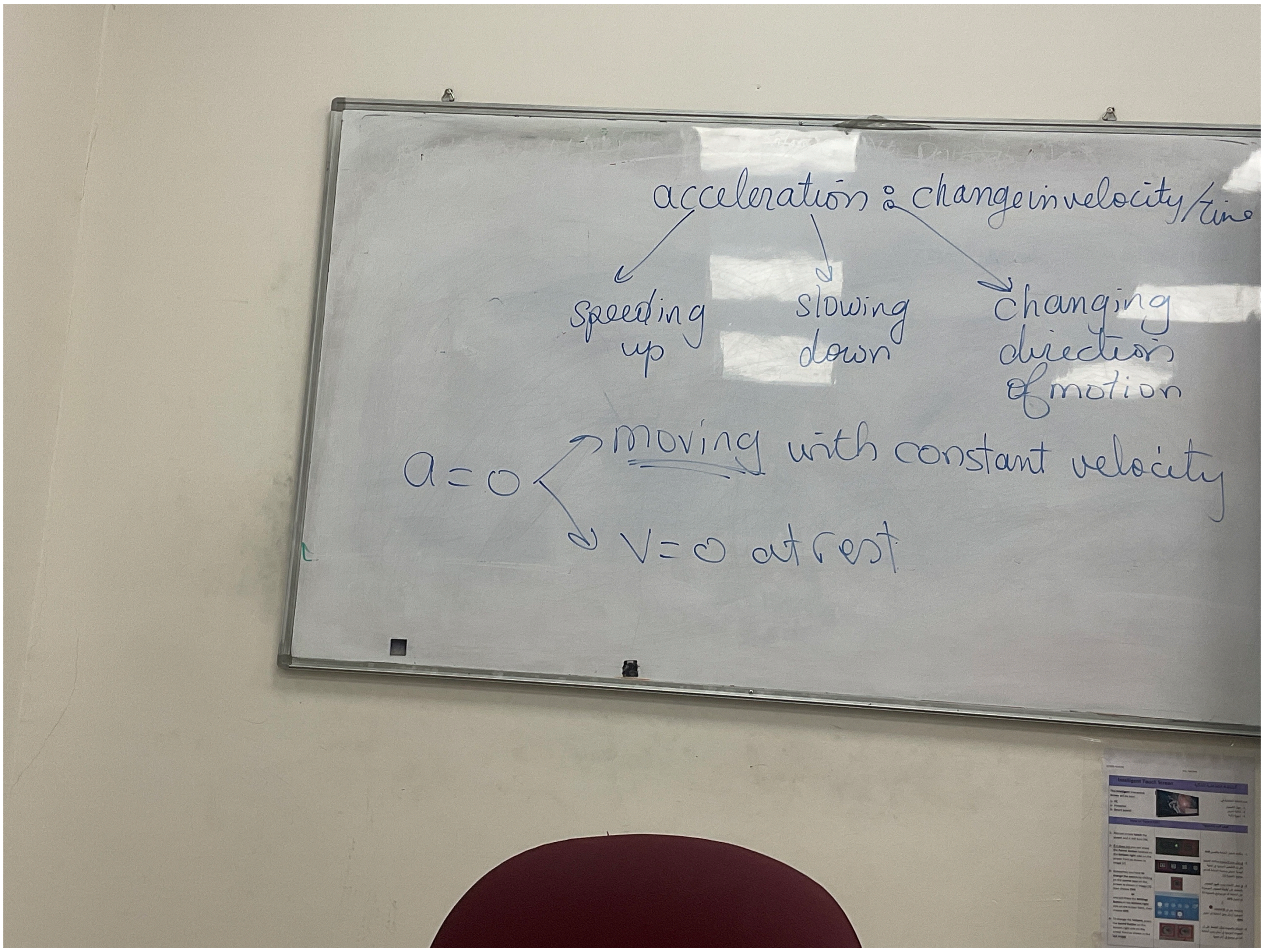
$$v_f = v_i + at$$

a = 0 → at rest
→ constant velocity

$$a = \frac{5m}{s^2} = \frac{5\,m/s}{s}$$



acceleration : change in velocity / time
a is +ve
a is -ve
Δ = Vf - Vi
speeding up +
in +ve direction
slowing down
in -ve direction
speeding up
in -ve direction
slowing down
in +ve direction


acceleration : change in velocity / time
speeding up
slowing down
changing direction of motion
a = 0
moving with constant velocity
v = 0 at rest

Exercises

Exercise: If the speed of a certain car at a certain moment is 12 m/s and its acceleration is 3 m/s², what will be the speed of the car 8 seconds later? (Ans. 36 m/s)

$v_f = v_i + at \Rightarrow v_f = 12 + 3(8) = 36\ m/s$

Exercise: A train slows down from a speed of 126 km/h to a speed of 54 km/h in 8 seconds.

a) What is the acceleration of the train? (note: mind the units!) (126 km/h = 35 m/s, 54 km/h = 15 m/s). (Ans. −2.5 m/s²; what does the negative sign mean?)

$a = \frac{v_f - v_i}{t} = \frac{15 - 35}{8} = -2.5\ m/s^2$

slows down, decelerating, a is −ve; mag → 2.5 m/s²; direction to the opp / −ve direction

b) If it continues to decelerate at the same rate, how long will it take to stop from its initial speed?

$v_f = 0$, $a = -2.5\ m/s^2$

$-2.5 = \frac{0 - 35}{t}$

$v_f = v_i + at$

$0 = 35 - 2.5(t) \rightarrow -35 = -2.5t$

$t = 14\ s$

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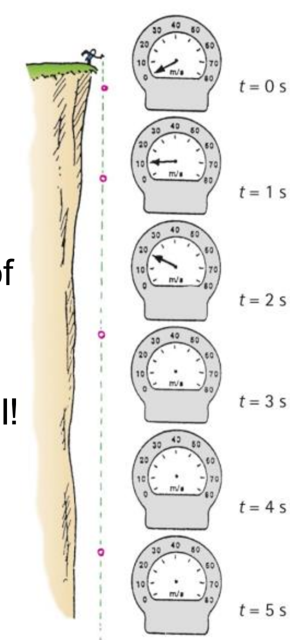
Acceleration

- Free fall:

  When **the only force acting on a falling object is gravity** (the weight), **with negligible air resistance**, the object is in a state of **free fall**.

  - An upward moving object under these conditions is also in free-fall!



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Extra Practice

1) A car slows down from $36\ \frac{m}{s}$ (v_i) to $72\ \frac{km}{h}$ (v_f) in 0.6 minutes

$v_f = 72\ \frac{km}{h} \div 3.6 = 20\ \frac{m}{s}$

$v_i = 36\ \frac{m}{s}$

$t = 0.6$ minutes $= 36$ seconds

→ acceleration

$a = \frac{v_f - v_i}{t} = \frac{20 - 36}{36}$

$= -0.444\ m/s^2$ → mag: $0.44\ m/s^2$
→ direction : −ve

→ how long will it take the car to stop from its initial speed

$v_f = 0\ m/s$

$v_i = 36\ m/s$

$t = ?$

$v_f = v_i + at$

$0 = 36 + (-0.44)(t)$

$\frac{-36}{-0.44} = \frac{-0.44t}{-0.44}$

$t = 81.8s$

2) what is the initial speed of a car accelerating by $4 m/s^2$ to reach $120 \frac{km}{h}$ in 8s

$$a = \frac{vf - vi}{t} \quad , \quad vf = vi + at$$

vi ?

$vf = 120 \frac{km}{h} \div 3.6$

$vf = 33.3 \ m/s$

$t = 8s$

$a = 4 m/s^2$

$33.3 = vi + 4(8)$

$33.3 = vi + 32$

$vi = 1.3 m/s$

3) calculate the final speed of a car moving at 90 $\frac{km}{h}$ and decelerating by 6m/s^2 in 3 seconds

$a = -6 m/s^2$

$v_f = ?$

$v_i = 90 \frac{km}{h} \div 3.6 = 25 m/s$

$s = 3 s$

$v_f = v_i + at$

$v_f = 25 + (-6)(3)$

$v_f = 25 - 18$

$v_f = 7 m/s$

Free fall

1) only force is weight / force of gravity

$W = mg$

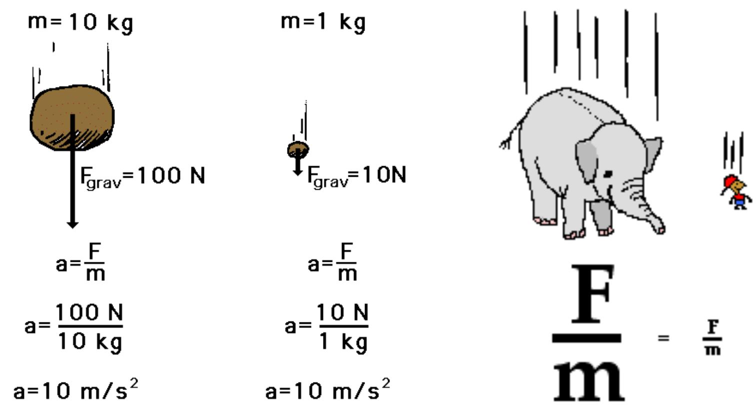
(N) ↓ kg → $g \approx 10 m/s^2$

2) Ignore air resistance (it is negligible)

Free Fall Acceleration

more SA = more air resistance

- Acceleration of free fall **does not** depend on mass. It is **constant.**



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Free Fall Acceleration

- Neglecting air resistance, all objects in free fall in the earth's gravitational field have a constant acceleration of magnitude:

$$g \cong 9.81\ m/s^2 \approx 10\ m/s^2$$

Direction of *g* is **always downwards** (towards earth's center).

- In other words, the speed of an object increases by 10 m/s each second while falling down and decreases by 10 m/s each second while moving up.
- Formula to use: Using $a = -g = -10\ \text{m/s}^2$ in the acceleration equation, we get: $v_f = v_i - gt$

(keep in mind v can be positive or negative)

- The **distance** travelled by a freely falling object released from rest is directly proportional to the square of the time of fall, In equation form: $d = \frac{1}{2}gt^2$

$\rightarrow -g = \frac{v_f - v_i}{t}$

$-gt = v_f - v_i$

$v_f = v_i - gt$

$d = \frac{1}{2}gt^2$

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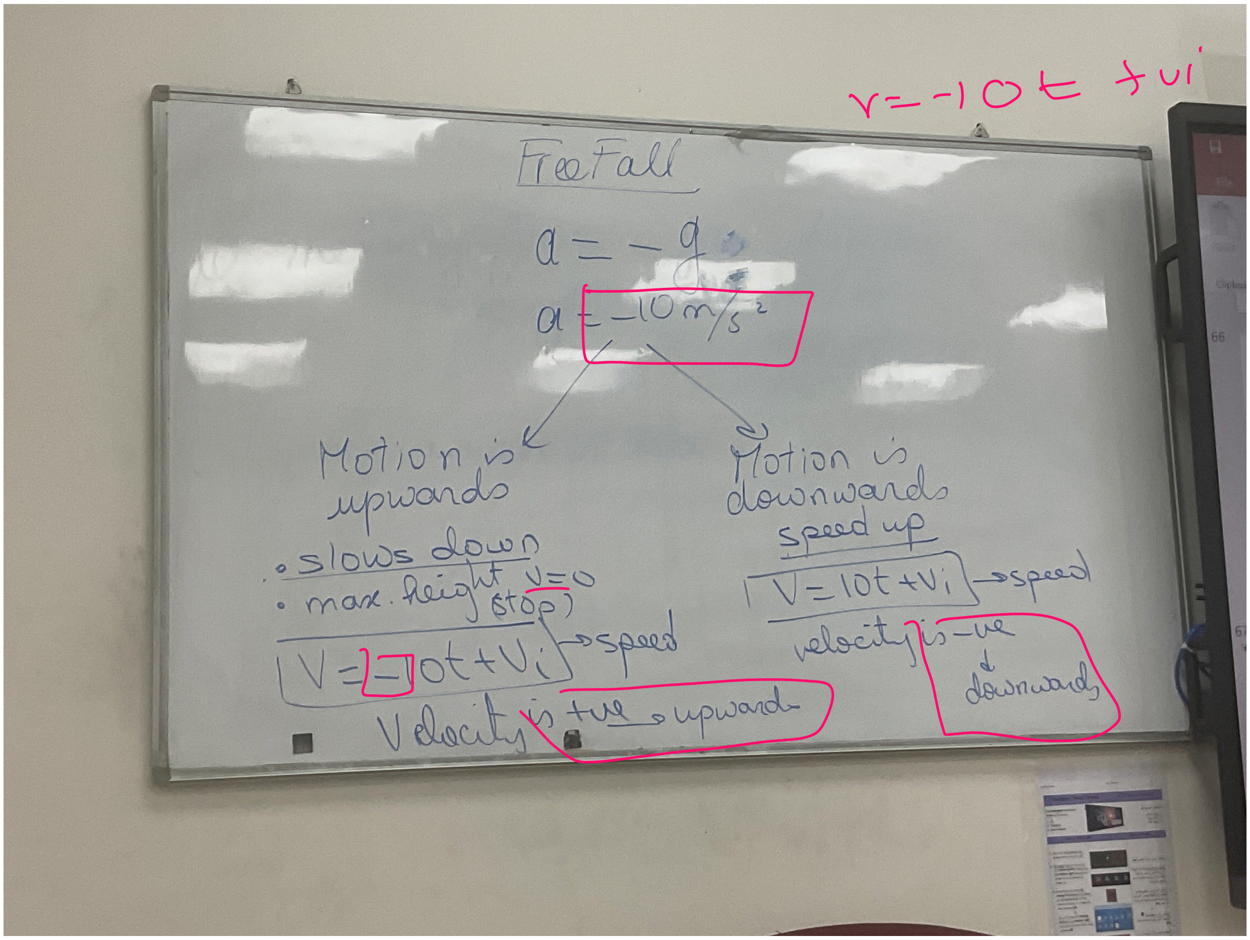

upwards   downwards

$-10t + v_i$ $10t + v_i$

Acceleration
CHECK YOUR NEIGHBOR

If a falling object gains 10 m/s each second it falls, its acceleration is

A. 10 m/s.

B. 10 m/s per second.

C. Both of the above.

D. Neither of the above.

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Acceleration
CHECK YOUR ANSWER

If a falling object gains 10 m/s each second it falls, its acceleration is

A. 10 m/s.

B. 10 m/s per second.

C. Both of the above.

D. Neither of the above.

Explanation:

It is common to express 10 m/s per second as 10 m/s/s, or 10 m/s^2.

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$v = 10t + v_i$

$v = 10(1) + 30$

$= 40$

Acceleration
CHECK YOUR NEIGHBOR

A free-falling object has a speed of 30 m/s at one instant. Exactly one second later its speed will be

A. the same.

B. 35 m/s.

C. more than 35 m/s.

D. 60 m/s.

$v = 10(1) + 30$

$= 40$

$v = 10t + v_i$

$v = 10(1) + 30$

$v = 40$ m/s

−10 if upwards

10 if downwards

$v = v_i + 10t$

$30 + 10(t) = 40$ m/s

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Acceleration
CHECK YOUR ANSWER

A free-falling object has a speed of 30 m/s at one instant. Exactly one second later its speed will be

A. the same.

B. 35 m/s.

C. more than 35 m/s.

D. 60 m/s.

Explanation:

One second later its speed will be 40 m/s, which is more than 35 m/s.

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Acceleration
CHECK YOUR NEIGHBOR

The distance fallen by a free-falling body

A. remains constant each second of fall.
B. increases each second when falling. → speed is increasing
C. decreases each second when falling.
D. None of the above.

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Acceleration
CHECK YOUR ANSWER

The distance fallen by a free-falling body

A. remains constant each second of fall.
B. increases each second when falling.
C. decreases each second when falling.
D. None of the above.

Explanation:

See Table 1.2 for verification of this. Falling distance ~ time squared.

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Exercises

$W = mg$

$W = 7 \times 10 = 70N$

Exercise: A 7-kg (mass) ball is thrown at 10 m/s straight upward. Neglecting air resistance, the net force that acts on the ball when it is half way to the top of its path is about

a) 10 N b) 5 N c) 35 N d) 70 N e) None of the above.

Exercise: An object is in a downward free-fall. At one instant, it travels at a speed of 37 m/s. Exactly 2 s later, its speed is about:

a) 37 m/s b) 10 m/s c) 57 m/s d) 17 m/s e) 20 m/s

$v = 10t + v_i = 10(2) + 37 = 57 m/s$

Exercise: A rock is thrown vertically into the air. At the top of its path, its acceleration in m/s^2 is about:

a) 10 b) Zero c) Between 0 and 10 d) Greater than 10

e) None of the above

magnitude of

$v = 10t + v_i$

Exercises

Exercise: A ball is thrown at a speed of 90 m/s directly upward from ground. (slows down)

a) What is the speed of the ball 7 seconds later?

$v = (-)10t + v_i$

$v = -10(7) + 90 \rightarrow v = -70 + 90, \; v = 20 m/s$

b) What is the time needed for the ball to reach the top point? $v = 0$

$0 = -10t + 90$

$10t = 90, \; t = 9s$

c) What is the speed of the ball 4 seconds after reaching the top point?

$0 = -10(4) + v_i$

$0 = -40, \; v_i = 40 m/s$

e) What is the ball's flight time?

$9s \times 2 = 18s$

$v = 0$, $t = 9s$, $v = 90 m/s$

$v = 0$, $t = 9s$, $v = -90 m/s$

flight time $= 9s + 9s = 18s$

$d = \frac{1}{2} g t^2$

Exercises

Exercise: A stone is dropped from rest from a large height. What is the distance traveled in the seventh second?

$d = \frac{1}{2}(10)(7)^2$

$d = 5(7)^2 \rightarrow d = 5 \times 49$

$d = 245 m$

Exercise: A ball thrown vertically upward from the ground is caught again by the thrower 12 seconds later. What is the maximum height reached by the ball?

$d = \frac{1}{2} g t^2$

$d = \frac{1}{2}(10)(6)^2$

77 $d = 5(6)^2$

$d = 5 \times 36$

$d = 180 m$

Free Fall

1) The only force is weight vertically downwards

2) $a = -g = -10 m/s^2$ downwards

motion ↑
slows down
$v = 0$ at max height

$v = -10t + v_i$ → speed

velocity +ve

motion ↓
speeds up

$v = 10t + v_i$ → speed

velocity -ve

---

* $v_i = 0$

distance in free fall (starting from rest)

$$d = \frac{1}{2} g t^2$$

$$= \frac{1}{2}(10) t^2$$

$$d = 5t^2$$

d → m, t → s

Extra Practice

slows down

1) A ball thrown upwards by a speed of 55 m/s

t

a) calculate its speed after 2s?

$v = -10t + v_i$

$v = -10(2) + 55$

$v = -20 + 55$

$v = 35\ m/s$

$v_f = -10t + v_i$

$v_f = -10(2) + 55$

$v = 0$

$v = 0$

b) what is the time needed to reach maximum height?

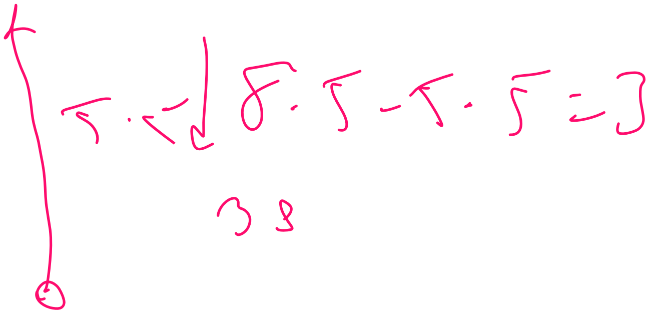
$v = -10t + v_i$

$0 = -10t + 55$

$0 = -10t + 55$

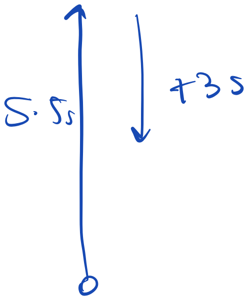
$\frac{-55}{-10} = \frac{-10t}{-10}$

$t = 5.5s$



c) what is the speed and velocity of the ball after 8.5s from throwing ball upwards

$8.5 - 5.5 = 3s$



$v_f = 10t + v_i$

$v_f = 10(3) + 0$

$= 30\ m/s$

speed

$v = 10t + v_i$

$v = 10(3) + 0$

$v = 30 m/s$

velocity

30m/s downwards