Essential Physics I

英語で物理学の

エッセンス I

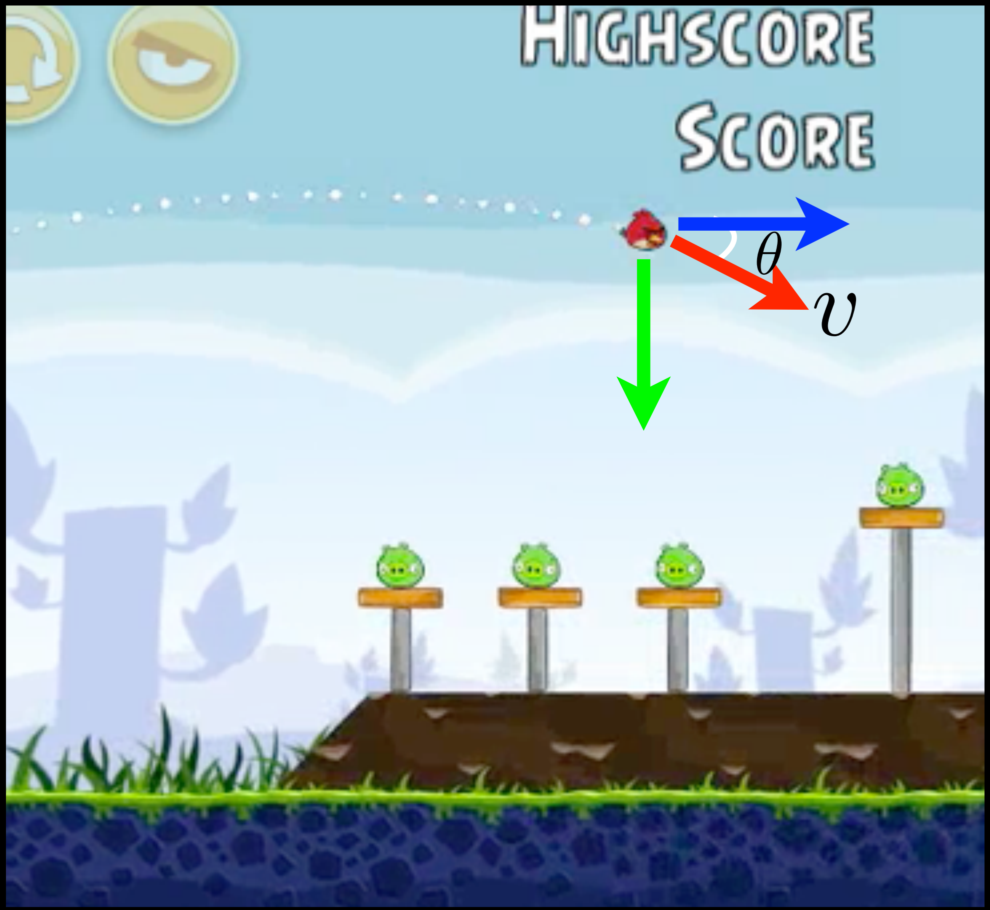
Lecture 4: 9-05-16

This lecture

- Understand why circular motion does not have constant acceleration
- Be able to calculate the orbit of a satellite
- Know Newton's 3 force laws
- Contradict conspiracy theories about the moon landing
- Know your real weight
- Calculate the motion of a flying pig

Review

Motion under gravity



Motion can be split into components

Constant acceleration equations can be used on each component.

$$v_{0,x} = v\cos\theta$$

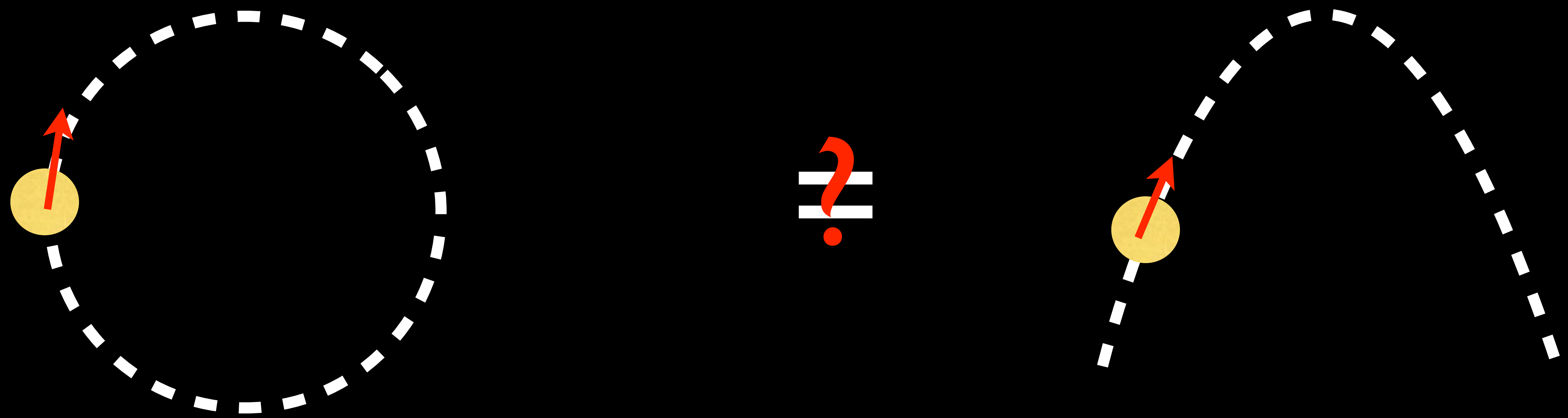
$$v_{0,y} = v\sin\theta$$

$$v_x = v_{x,0} + a_x t$$
$$x = x_0 + v_{x,0}t + \frac{1}{2}a_x t^2$$
$$v_x^2 = v_{x,0}^2 + 2a_x(x - x_0)$$

$$v_y = v_{y,0} + a_y t$$
$$y = y_0 + v_{y,0}t + \frac{1}{2}a_y t^2$$
$$v_y^2 = v_{y,0}^2 + 2a_y(y - y_0)$$

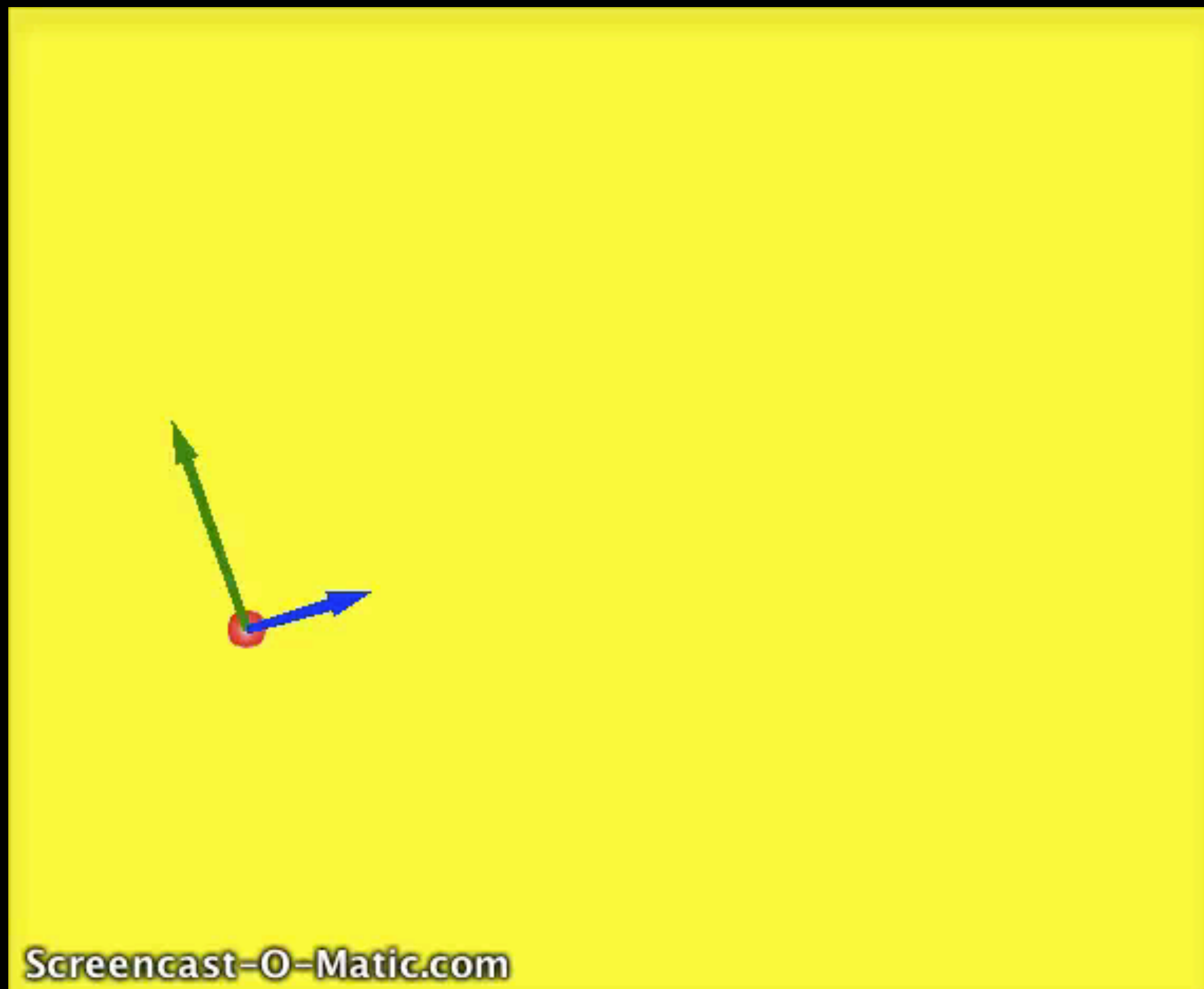
Circular motion

Is circular motion the same as projectile motion?



Circular motion

uniform motion



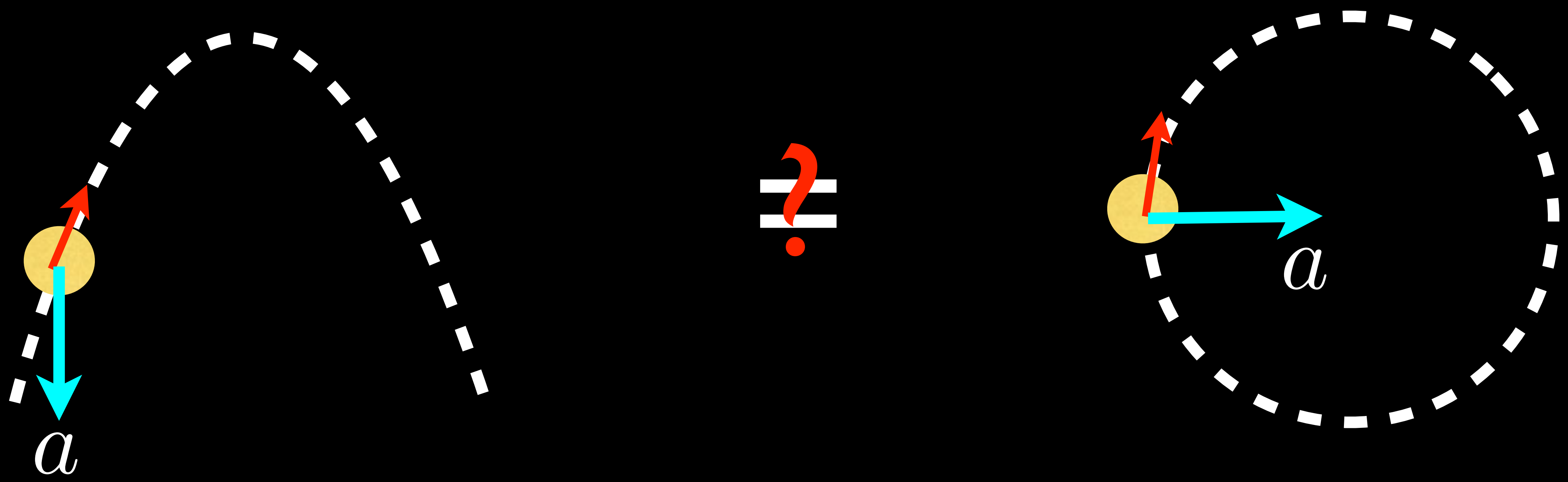
$\bar{v}$ velocity vector

$\bar{a}$ acceleration vector

} Magnitude constant.
Direction changes.

Circular motion

Is circular motion the same as projectile motion?



In both cases, acceleration magnitude is constant.

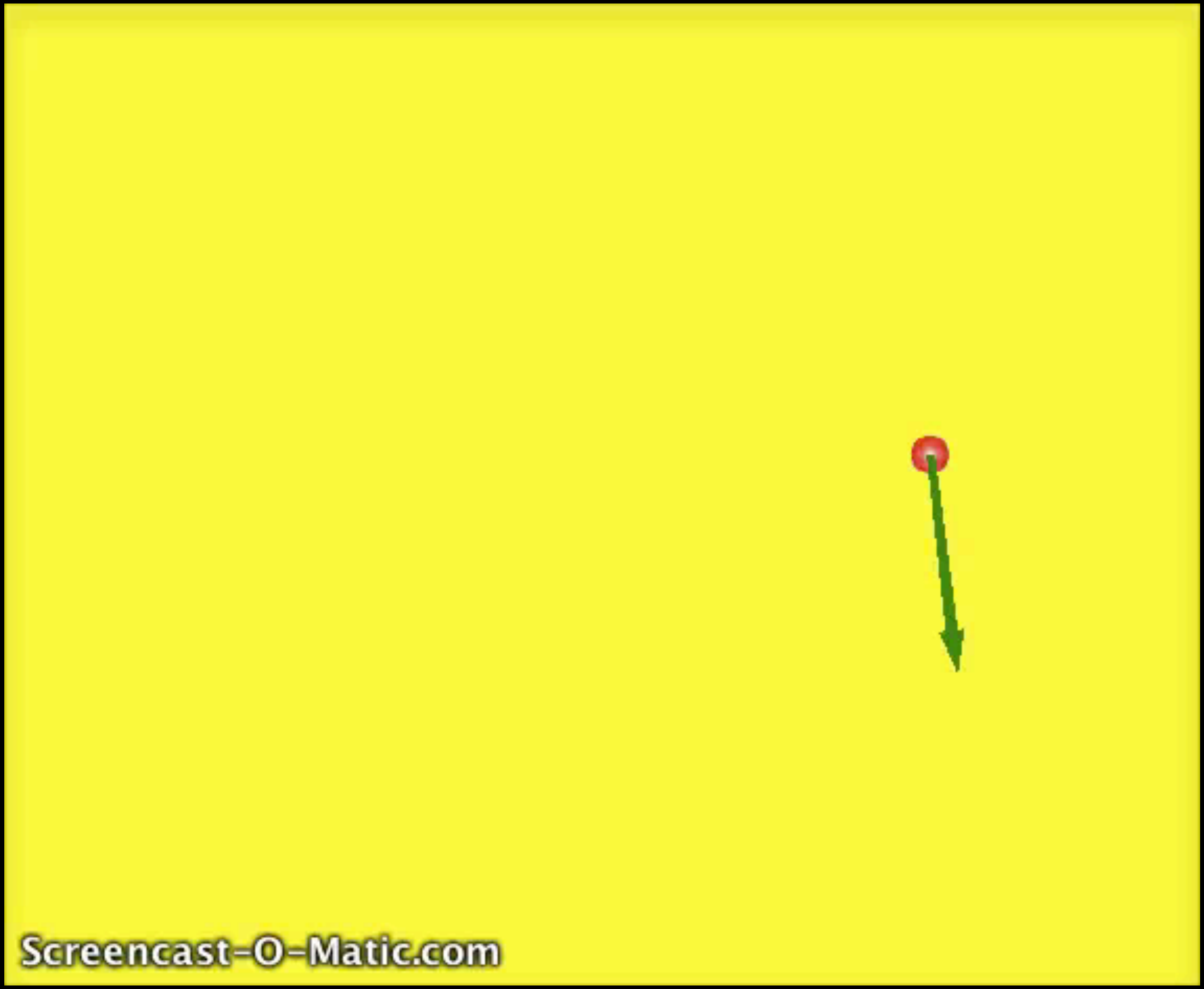
But in circular motion, the vector direction changes.

Therefore, no! Circular motion is different from projectile motion.

Circular motion acceleration is called the centripetal acceleration.

Circular motion

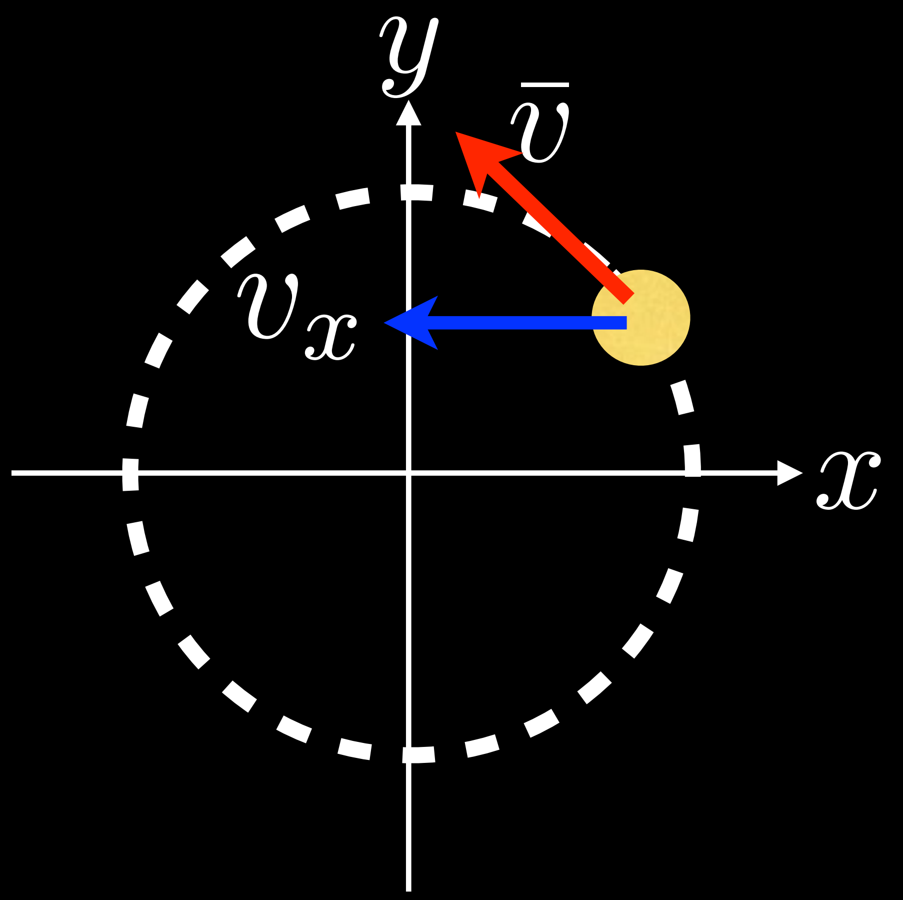
uniform motion



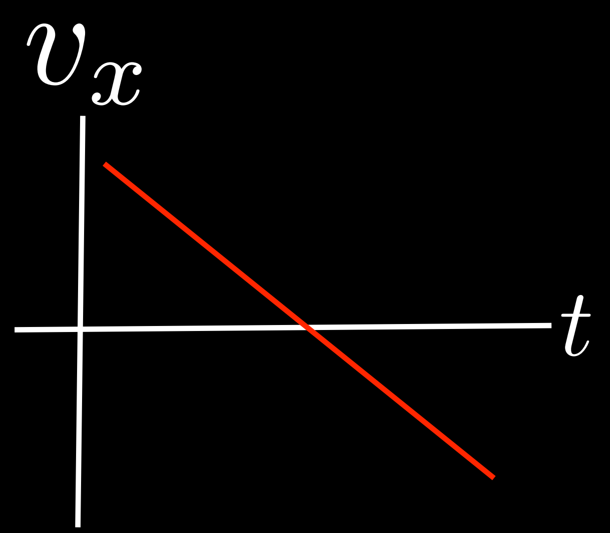

$\bar{v}$ velocity vector

Circular motion

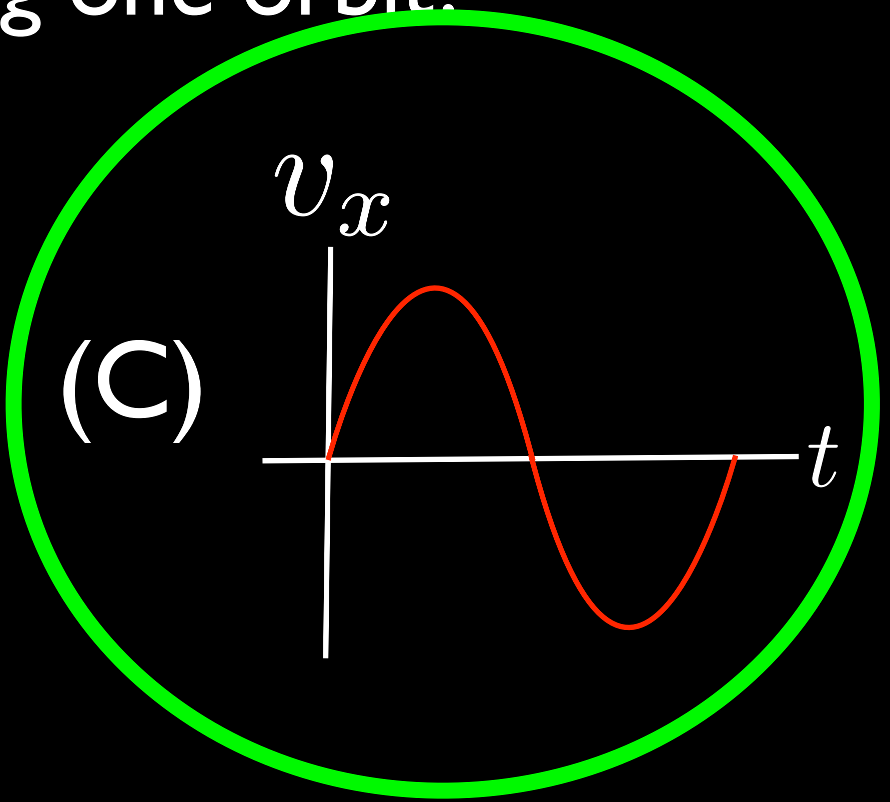
What does the x-component of the velocity look like during one orbit?



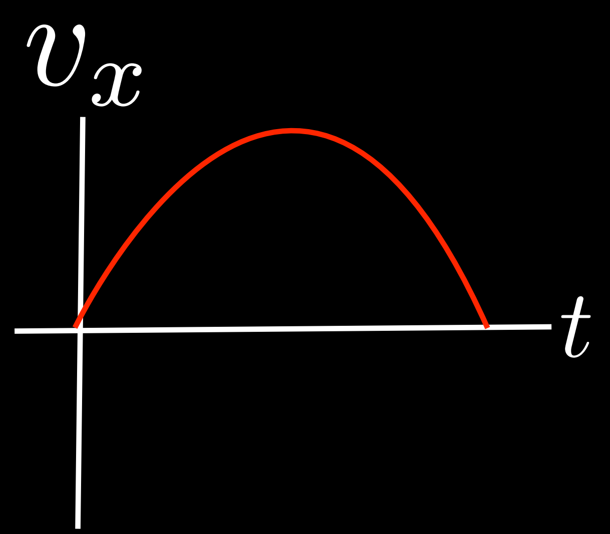
(A)



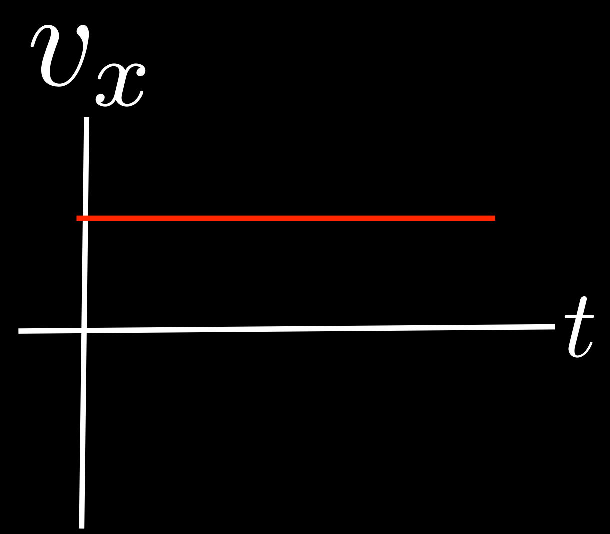
(C)



(B)

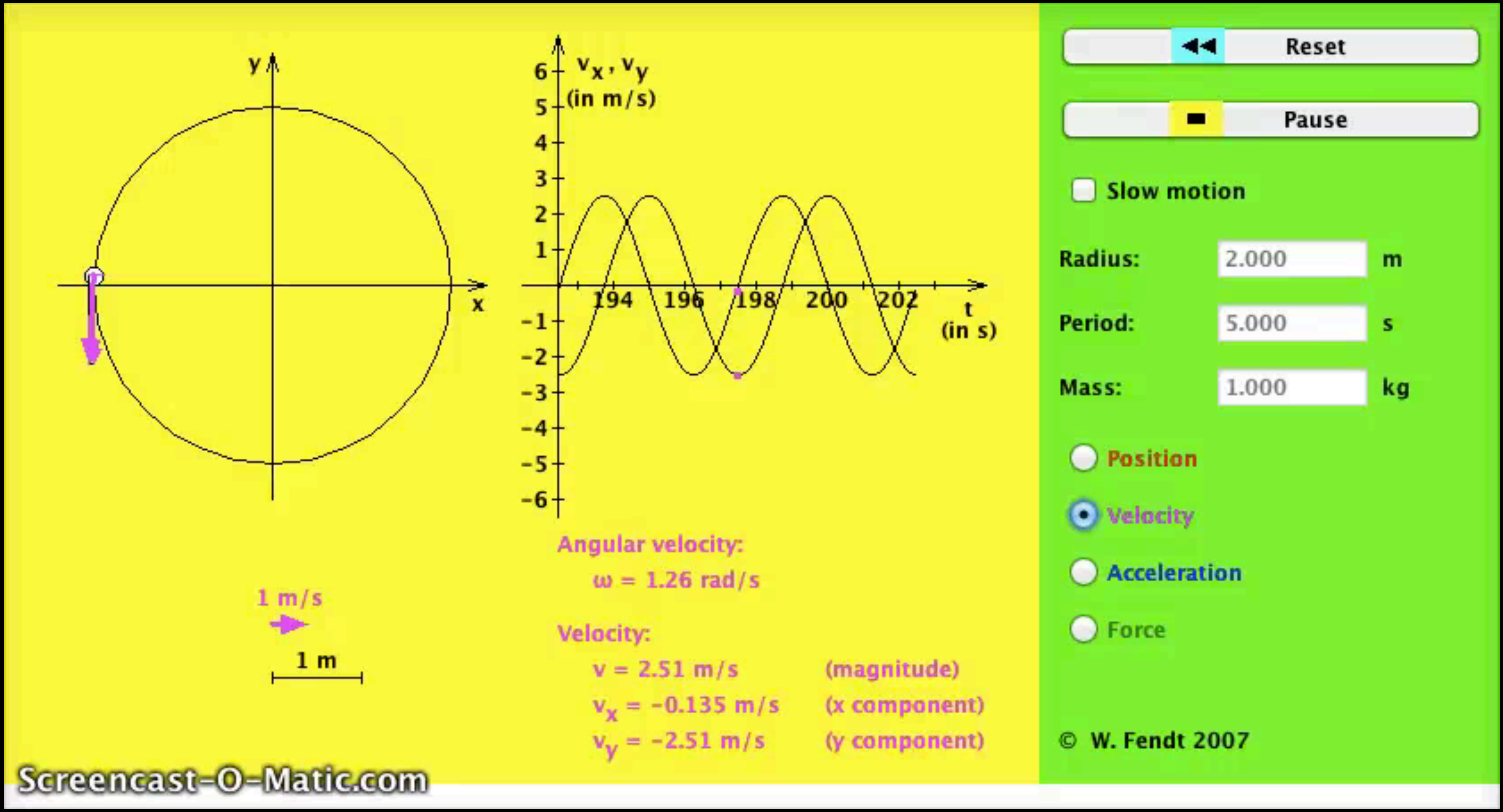


(D)



Circular motion

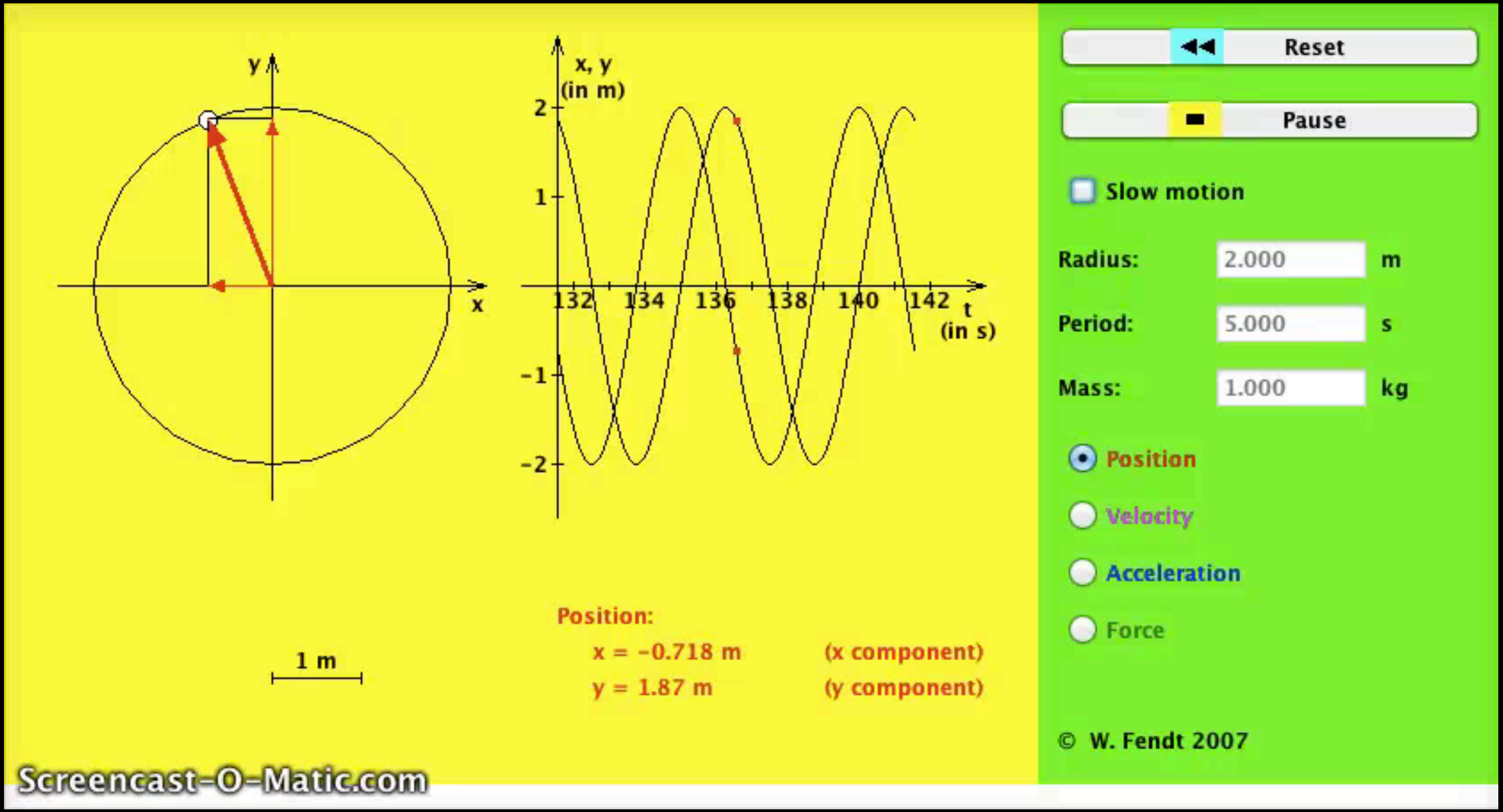
Velocity components:



$$v = \sqrt{v_x^2 + v_y^2}$$

Circular motion

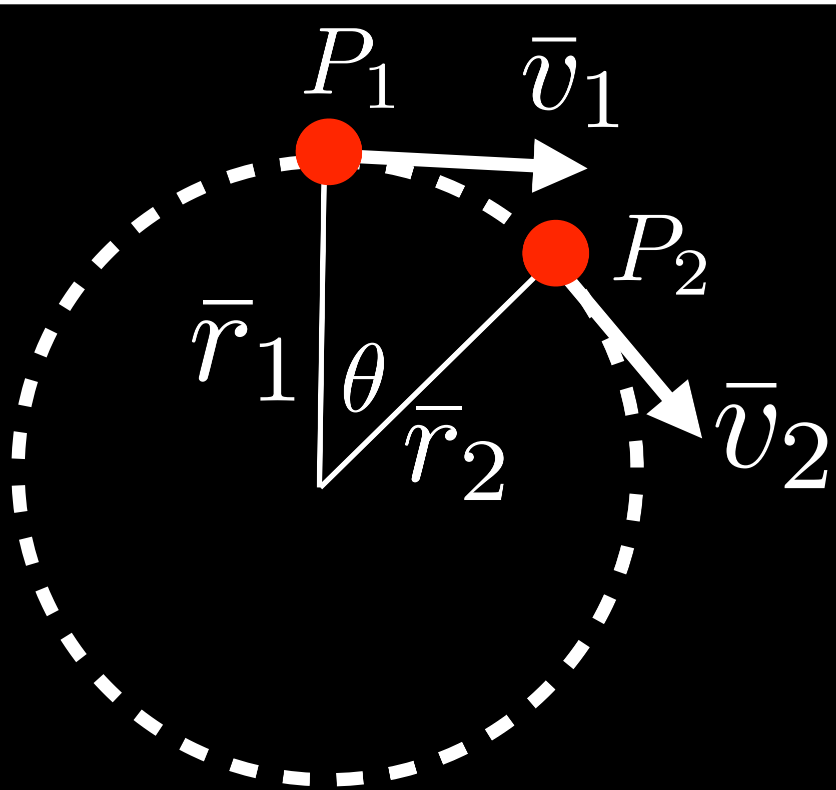
Position components:



$$r = \sqrt{x^2 + y^2}$$

Circular motion

uniform motion



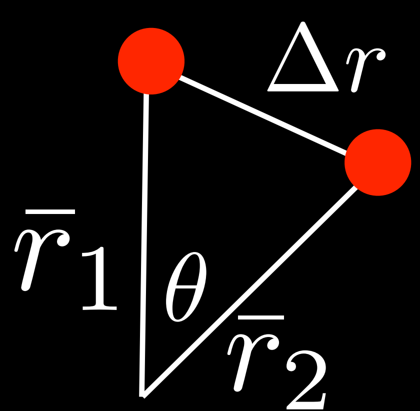
$$|\bar{r}_1| = |\bar{r}_2| = r$$
$$|\bar{v}_1| = |\bar{v}_2| = v$$

magnitude equal

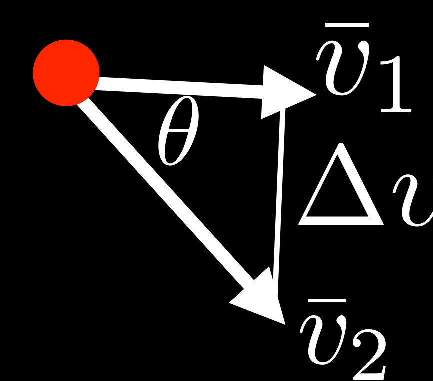
$$\bar{r}_1 \neq \bar{r}_2$$
$$\bar{v}_1 \neq \bar{v}_2$$

direction different

From diagram:

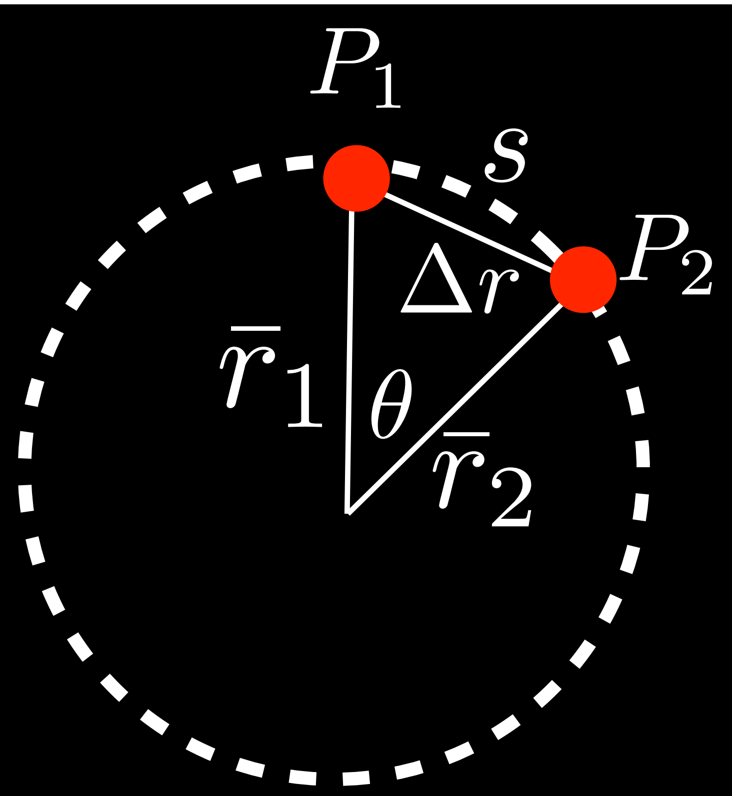


and since $\bar{v}$ is perpendicular (90° angle) to $\bar{r}$:



$$\frac{\Delta v}{v} = \frac{\Delta r}{r}$$

Circular motion



If θ is small, $\Delta r \simeq s$, curve distance between P_1 and P_2.

$$s = \text{distance travelled in time, } \Delta t$$
$$= v\Delta t$$

Therefore:

$$\frac{\Delta v}{v} = \frac{\Delta r}{r} \simeq \frac{v\Delta t}{r}$$

$$\underbrace{\frac{\Delta v}{\Delta t}}_{a} \simeq \frac{v^2}{r} \longrightarrow$$

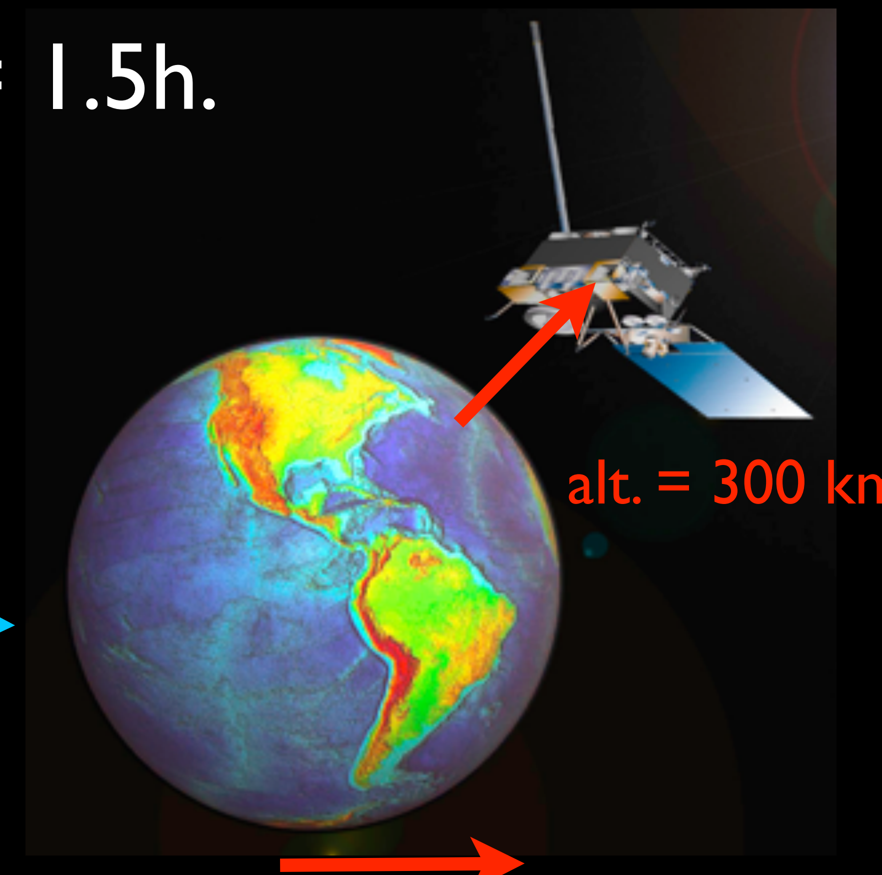
$$a = \frac{v^2}{r}$$

uniform circular motion

Circular motion

A satellite at altitude 300 km has a period T = 1.5h.

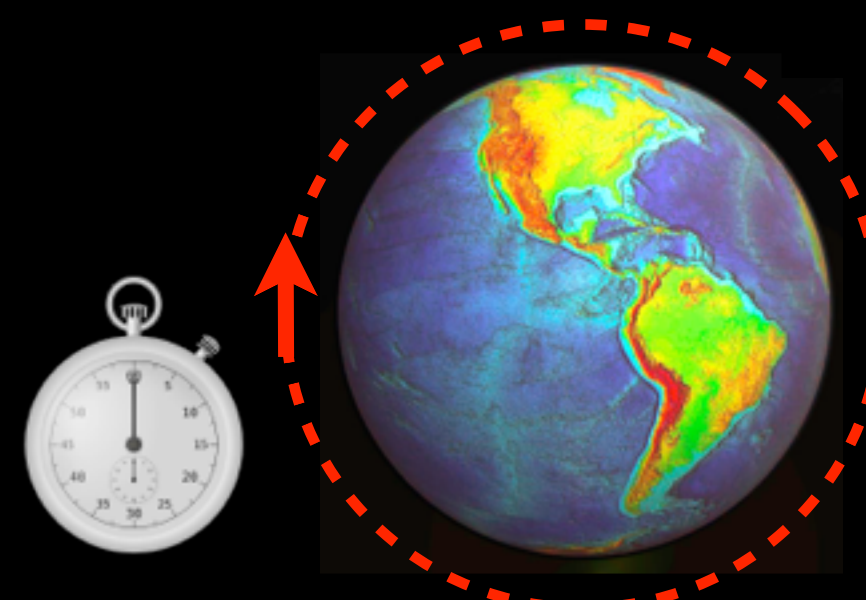
What is its centripetal acceleration?



$R_E = 6.37 \times 10^6 \mathrm{m}$

height above planet surface

Time for 1 orbit around planet

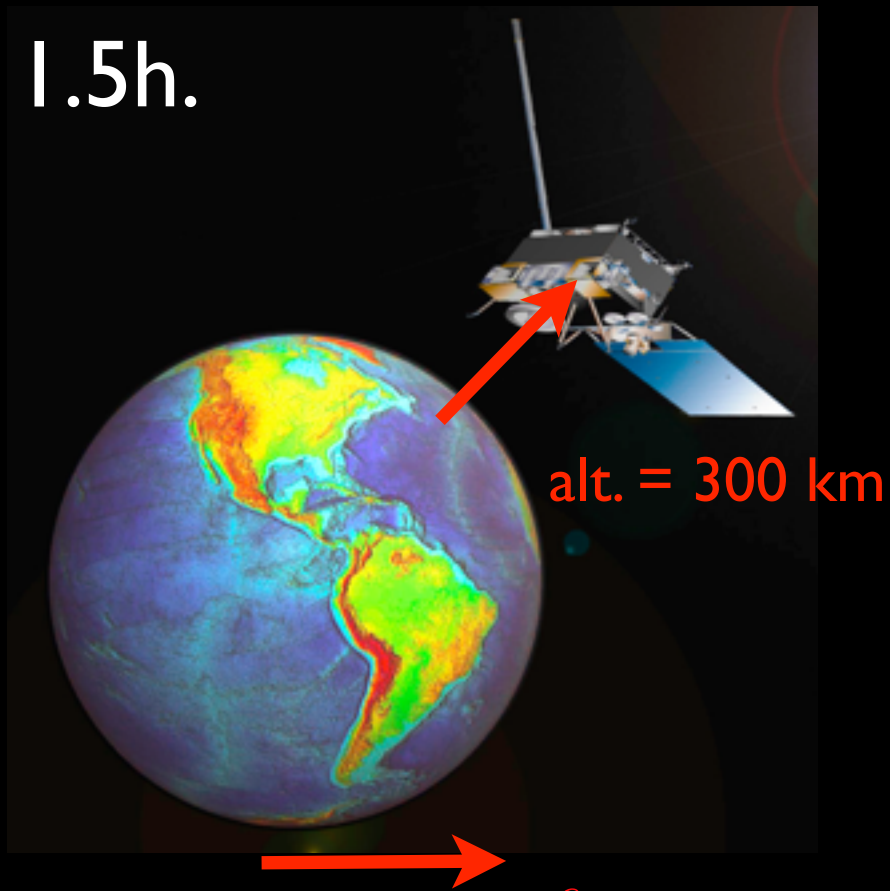


Circular motion

Example

A satellite at altitude 300 km has a period T = 1.5h.

What is its centripetal acceleration?



$R_E = 6.37 \times 10^6 \text{m}$

$$r = R_E + \text{altitude}$$

$$= (6.37 \times 10^6 \text{m}) + (300\text{km}) \times \frac{1 \times 10^3 \text{m}}{1\text{km}}$$

$$= 6.67 \times 10^6 \text{m}$$

one orbit $= 2\pi r = 2\pi(6.67 \times 10^6)\text{m}$

$$T = 1.5\text{h} = 1.5\text{h} \times \frac{3600\text{s}}{1\text{h}} \text{ s}$$

$$v = \frac{2\pi r}{T} = 7,757 \text{m/s}$$

$$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2} = 9.0 \text{m/s}^2$$

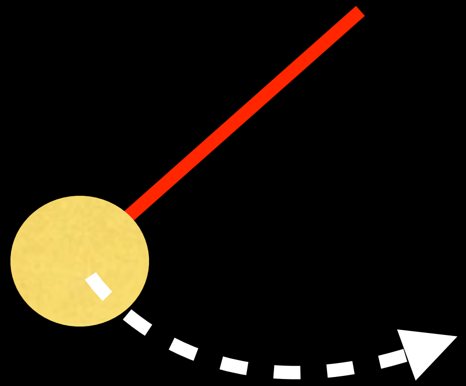
Why not 9.81m/s^2 ?

Circular motion

Quiz

A tethered ball moves in a horizontal circle of radius 2 m.
It makes one revolution in 3 s.

Find its acceleration.



$$a = \frac{v^2}{r}$$

Circular motion

A tethered ball moves in a horizontal circle of radius 2 m.
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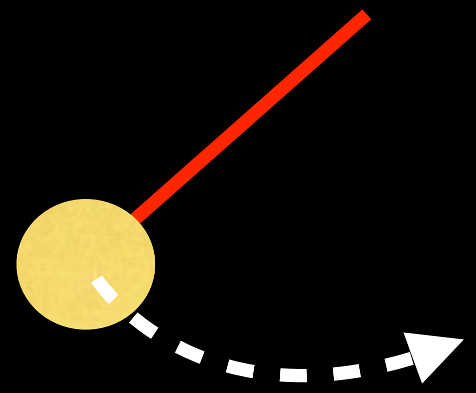
Find its acceleration.



(a) $8.76 \mathrm{m/s^2}$ direction outwards

(b) $8.76 \mathrm{m/s^2}$ direction inwards

(c) $8.76 \mathrm{m/s^2}$ direction same as velocity

(d) $62.3 \mathrm{m/s^2}$ direction outwards

(e) $62.3 \mathrm{m/s^2}$ direction inwards

(f) $62.3 \mathrm{m/s^2}$ direction same as velocity

Circular motion

Quiz

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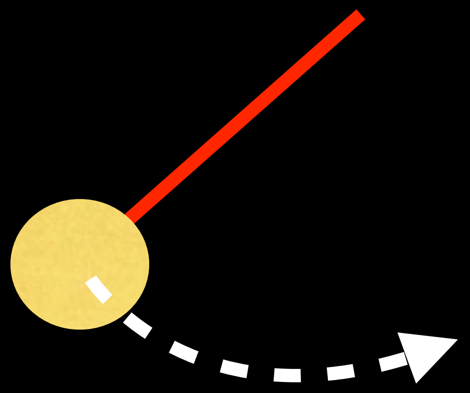
It makes one revolution in 3 s.

Find its acceleration.

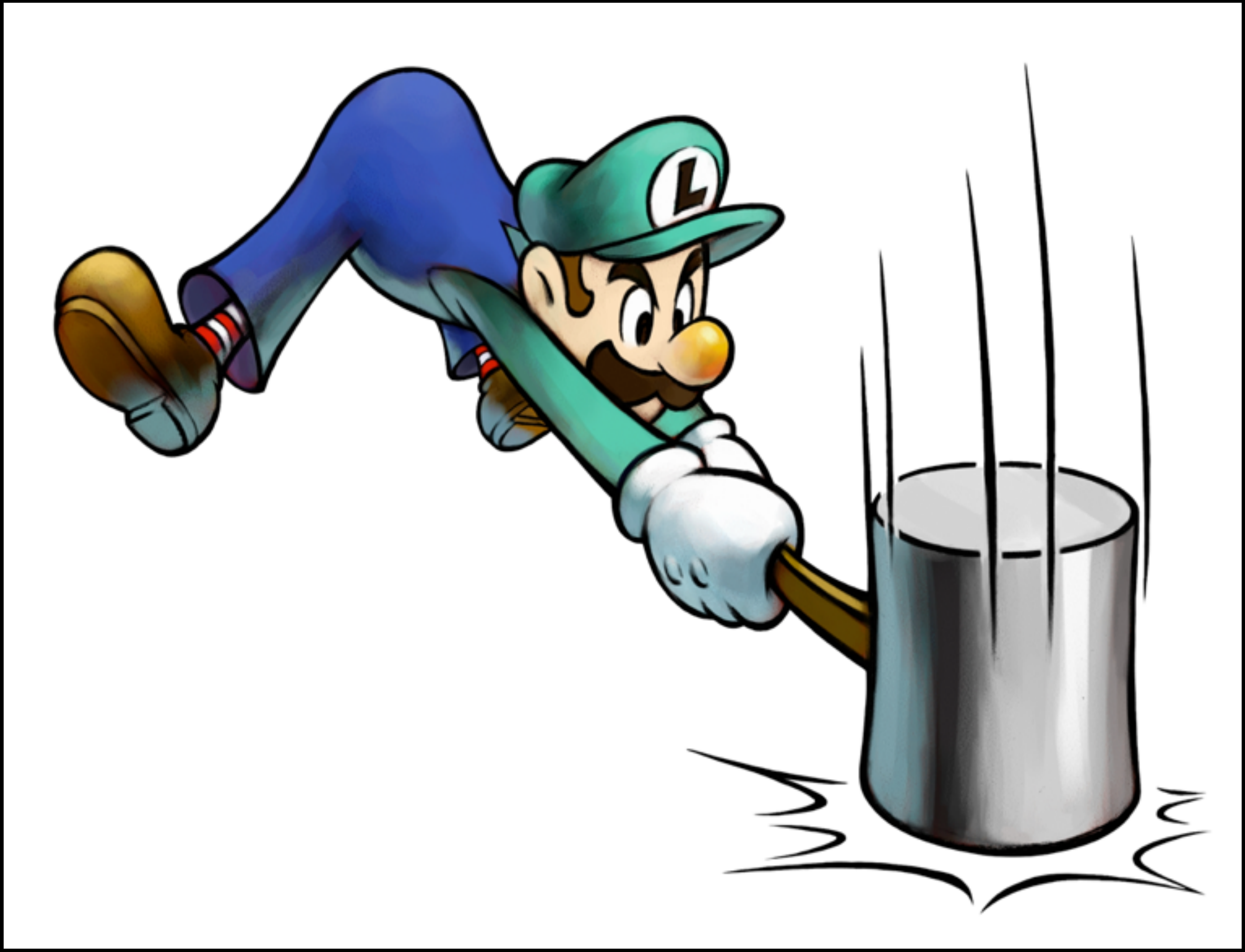


$$v = \frac{2\pi r}{T} = \frac{2\pi(2\,\mathrm{m})}{3\,\mathrm{s}} = 4.19\,\mathrm{m/s}$$

$$a = \frac{v^2}{r} = \frac{(4.19\,\mathrm{m/s})^2}{2\,\mathrm{m}} = 8.76\,\mathrm{m/s}^2$$

$$a = \frac{v^2}{r}$$

Forces



Forces

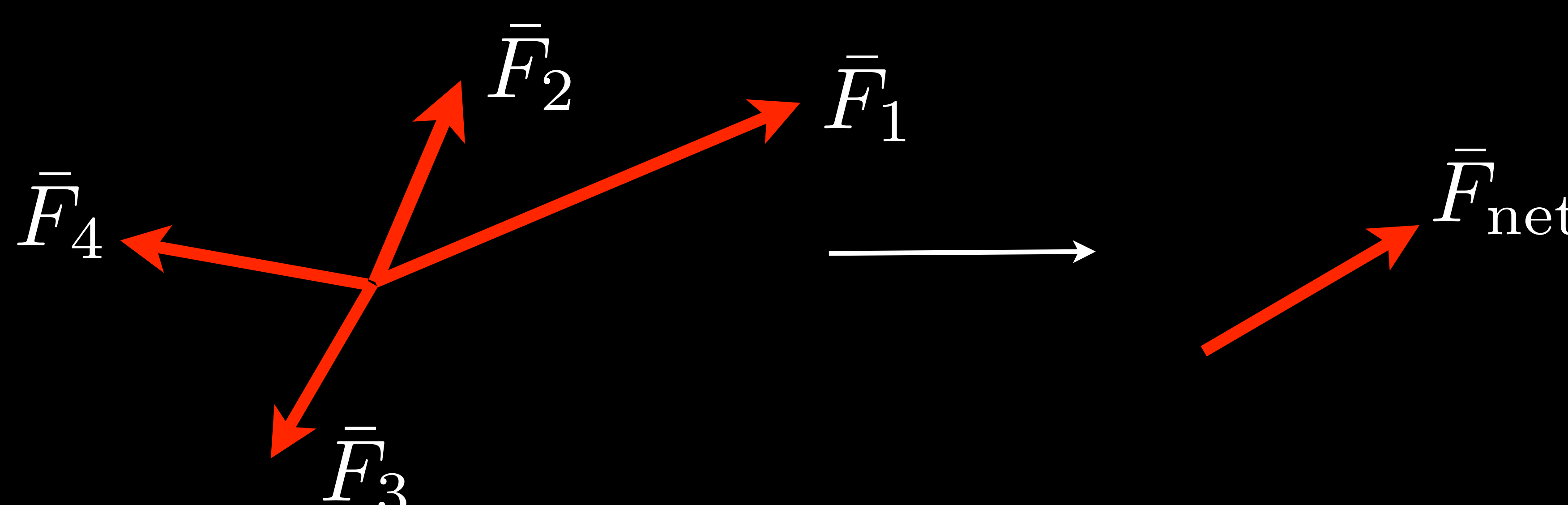
What are forces?

Forces change motion:

Forces are vectors:

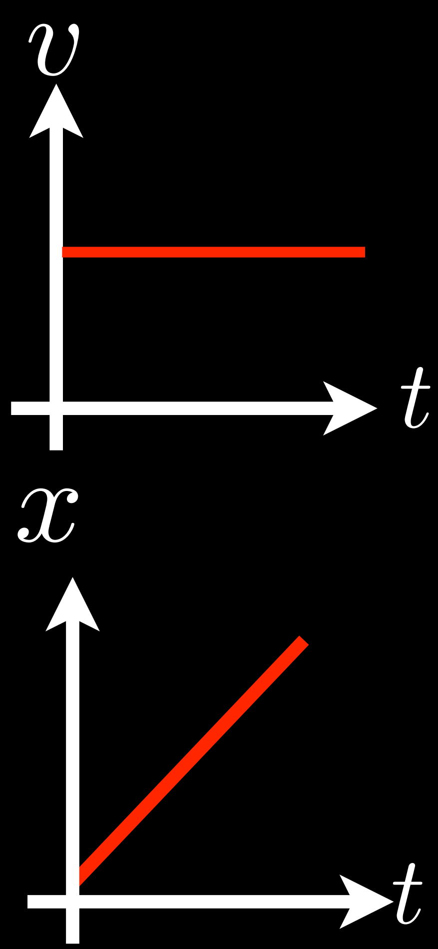
magnitude & direction

can be added



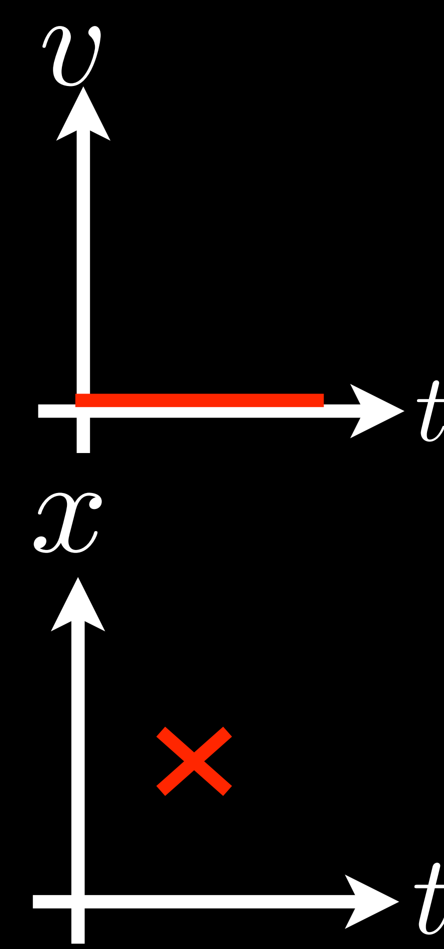
Newton's First Law

"A body in uniform motion remains in uniform motion,
and a body at rest remains at rest,
unless acted on by a nonzero net force."



No forces

constant velocity



If you don't change it, it won't change

Forces

Quiz

Newton's First Law

But a rolling ball comes to a stop. Why?

(A) there always has to be a continual force to keep moving

(B) there is a force acting that stops the ball

(C) because "rolling" is a different kind of motion

(D) Newton's laws don't always apply

Forces

Quiz

Newton’s First Law

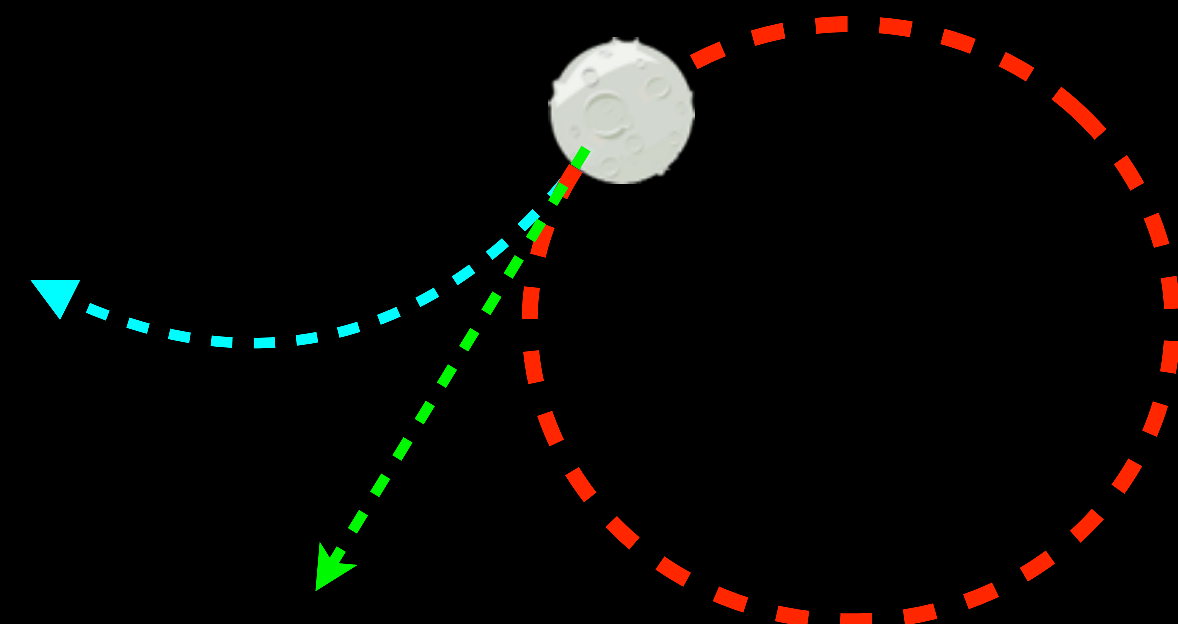
If the Earth disappeared, what path would the moon follow?

(A) continue on red path

(B) move on green path

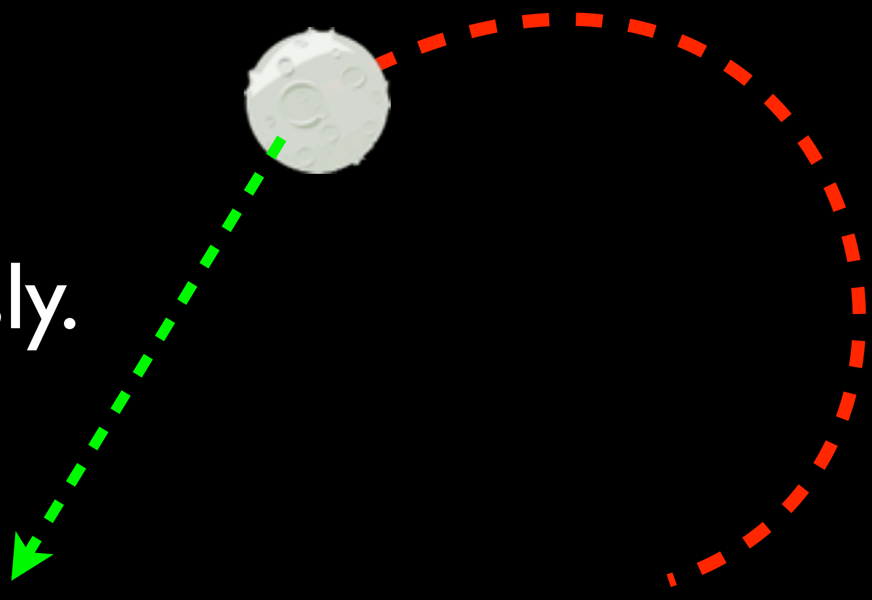
(C) move on blue path

(D) stop



Newton's First Law

Circular motion is not uniform.



$\bar{r}, \bar{v}, \bar{a}$ vectors change direction continuously.

Therefore, circular motion requires a net force .

The moon would move with the velocity it had at the point the Earth vanished.

Forces

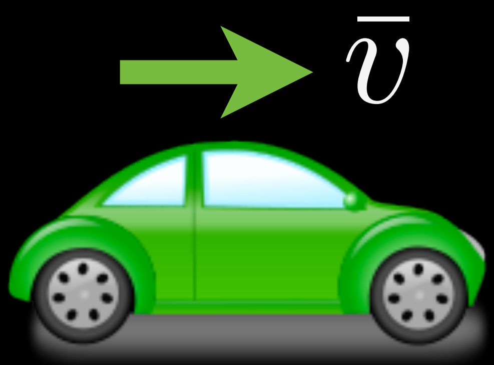
Rules for forces

Newton's First Law

If Newton's first law applies, we are in an inertial reference frame.

Rotating frames are not inertial.

A car moving at a constant velocity is an inertial frame.



Newton's laws will hold inside and outside the car.

Experiments done inside and outside the car will give the same result.

Forces

Quiz

Newton's First Law

Apollo 11 landed on the moon in 1969.

Some people have claimed the moon landing was fake.

One reason they give is that the American flag waves, yet there is no wind on the moon.

Why is this reason invalid?

(A) There is wind on the moon.

(B) The flag moves as the astronauts set it down, and doesn't stop.

(C) Oh my God! There was no moon landing!

(D) The flag doesn't wave, the video was bad.

Forces

Newton's 2nd Law

"The rate at which a body's momentum changes is equal to the net force acting on the body."

Quantifies the effect of force on motion.

calculate exactly

The effect of a force depends on an object's mass and velocity

The product of mass and velocity is momentum $\bar{p} = m\bar{v}$

multiply

$$\bar{F}_{\text{net}} = \frac{d\bar{p}}{dt} = \frac{(m\bar{v})}{dt} = m\frac{d\bar{v}}{dt} = m\bar{a}$$

Forces

Rules for forces

Newton's 2nd Law

$$\bar{F}_{\text{net}} = m\bar{a}$$

If $\bar{F}_{\text{net}} = 0$, then $\bar{a} = 0$ ⟶ **Newton's First Law**

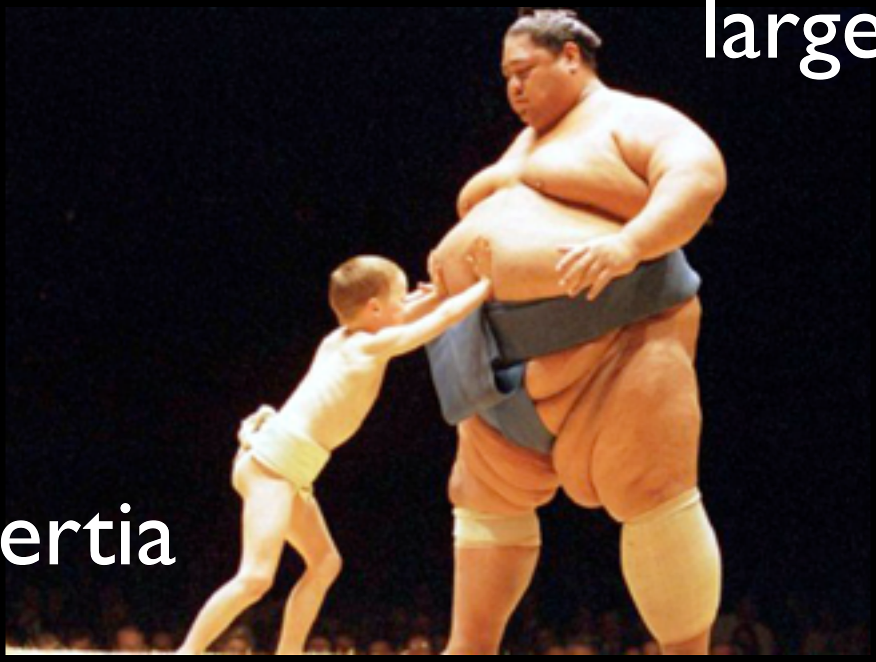
Nobody likes change.... The resistance to movement is called inertia.

The more difficult it is to change the motion of an object the more inertia it has.

$$\bar{a} = \frac{\bar{F}_{\text{net}}}{m}$$

Forces have a smaller effect if the mass is big

large inertia



small inertia

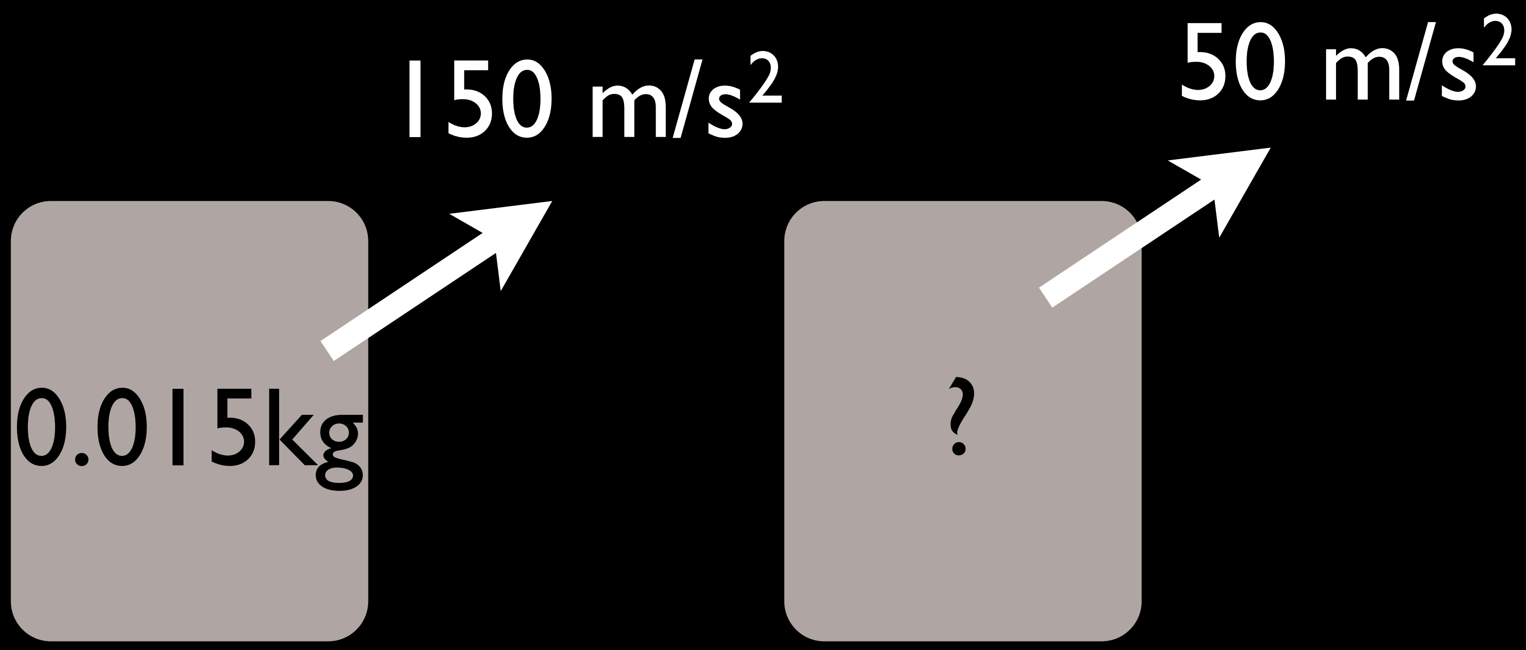
mass measures inertia

Forces

Quiz

Newton’s 2nd Law

A force produces an acceleration of 150 m/s^2

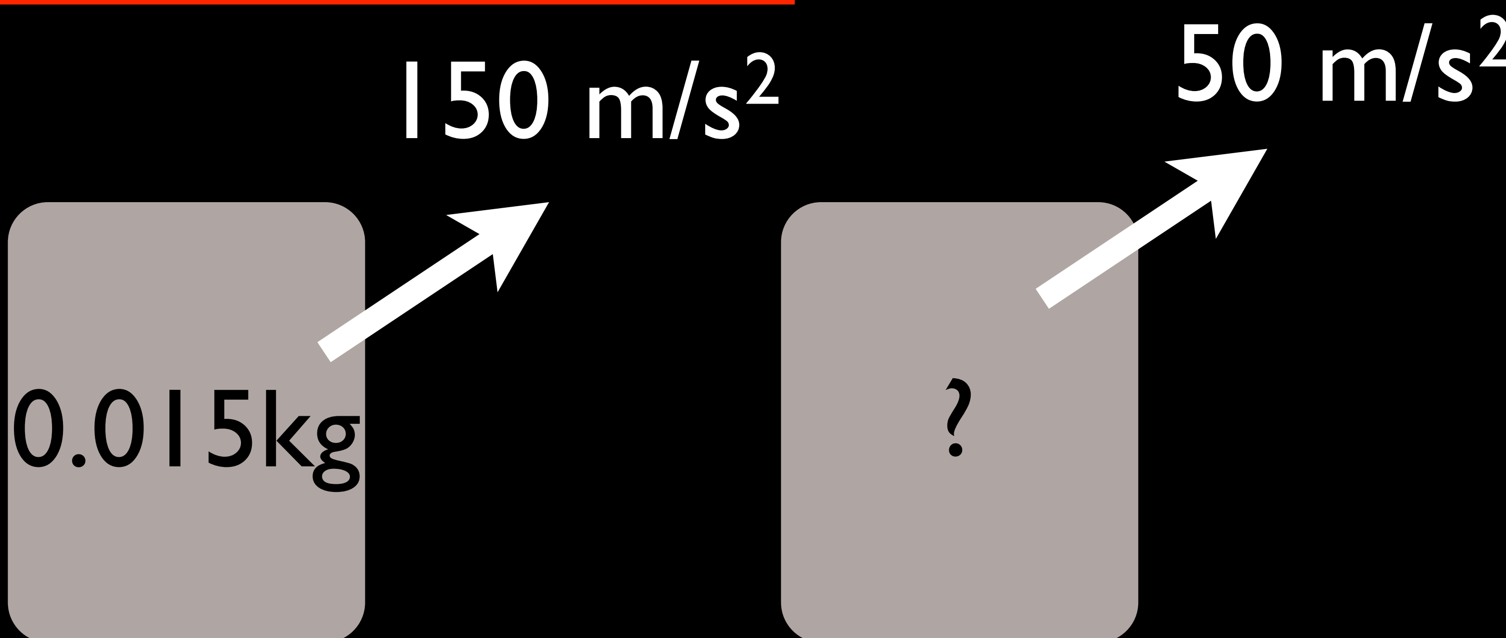


The same force gives a 2nd can an acceleration of 50 m/s^2. What is the mass of the second can?

Forces

Quiz

Newton's 2nd Law



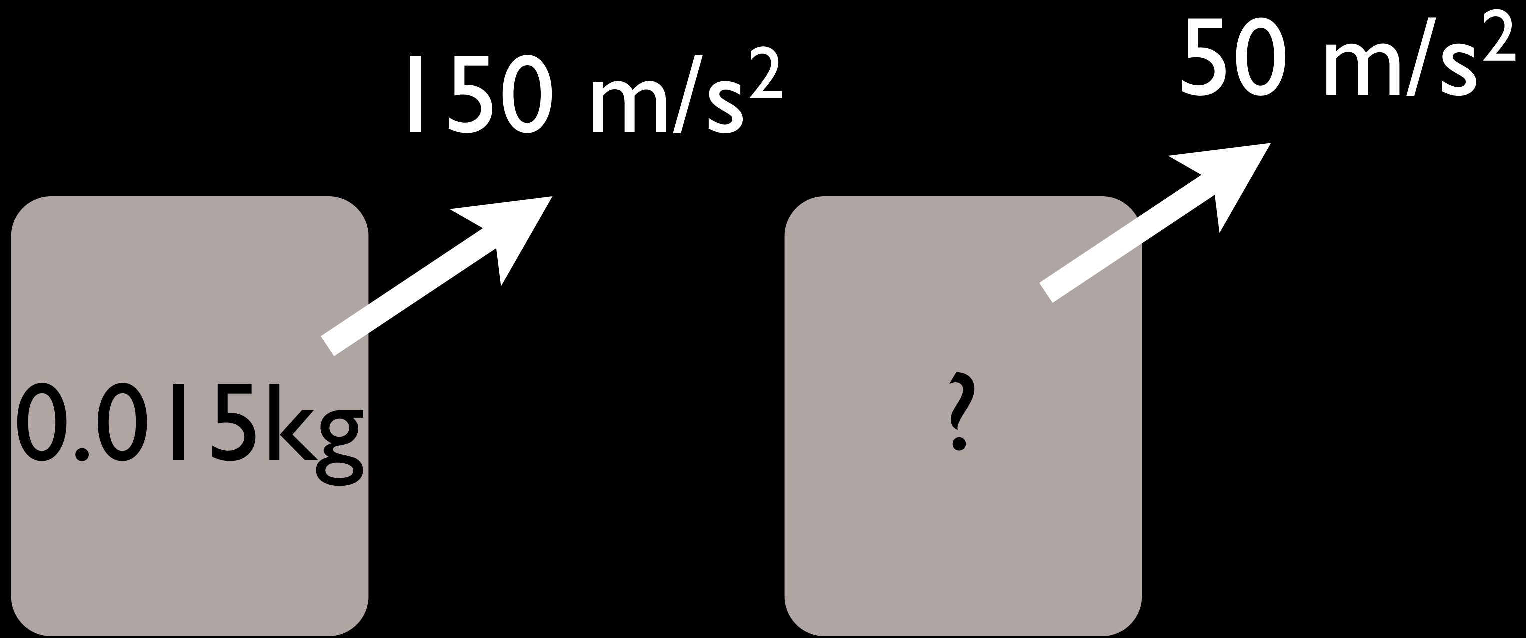
The same force gives a 2nd can an acceleration of 50 m/s^2. What is the mass of the second can?

(a) 0.005 kg (b) 0.015 kg (c) 0.045 kg (d) 22.2 kg

Forces

Quiz

Newton's 2nd Law



The same force gives a 2nd can an acceleration of 50 m/s^2. What is the mass of the second can?

$$\bar{F} = m_1 \bar{a}_1 = m_2 \bar{a}_2$$

$$0.015\,\mathrm{kg} \times 150\,\mathrm{m/s^2} = m_2 \times 50\,\mathrm{m/s^2}$$

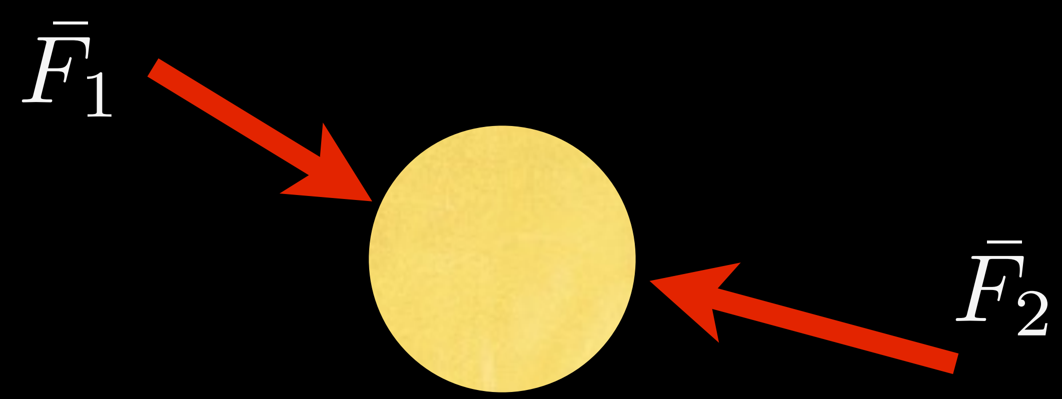
$$m_2 = \frac{0.015\,\mathrm{kg} \times 150\,\mathrm{m/s^2}}{50\,\mathrm{m/s^2}}$$

Forces

Example

Newton's 2nd Law

A particle of mass 0.4 kg is subjected to 2 forces, $\bar{F}_1 = 2\mathrm{N}\bar{i} - 4\mathrm{N}\bar{j}$ and $\bar{F}_2 = -2.6\mathrm{N}\bar{i} + 5\mathrm{N}\bar{j}$.



Particle starts from rest ($v = 0$) at the origin ($x = 0$) at $t = 0$, find its position and velocity at $t = 1.6\mathrm{s}$

Forces

Newton's 2nd Law

How to solve:  motion from a constant force

Use $\bar{F}_{\text{net}} = m\bar{a}$: constant force → constant acceleration

↓

constant acceleration equations

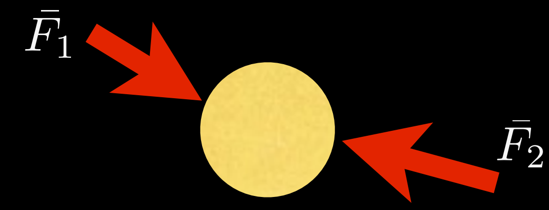
$$v = v_o + at$$

$$x = x_o + v_o t + \frac{1}{2}at^2$$

$$v^2 = v_o^2 + 2a(x - x_o)$$

Forces

Newton's 2nd Law



A particle of mass 0.4 kg is subjected to 2 forces, $\bar{F}_1 = 2\text{N}\bar{i} - 4\text{N}\bar{j}$ and $\bar{F}_2 = -2.6\text{N}\bar{i} + 5\text{N}\bar{j}$.

Particle starts from rest $(v = 0)$ at the origin ($x = 0$) at $t = 0$, find its position and velocity at $t = 1.6\text{s}$

Net force: $\bar{F}_{\text{net}} = \bar{F}_1 + \bar{F}_2 = (2\text{N}\bar{i} - 4\text{N}\bar{j}) + (-2.6\text{N}\bar{i} + 5\text{N}\bar{j})$

$$= -0.6\text{N}\bar{i} + 1.0\text{N}\bar{j}$$

From Newton's 2nd: $\bar{a} = \dfrac{\bar{F}_{\text{net}}}{m} = \dfrac{-0.6\text{N}\bar{i} + 1.0\text{N}\bar{j}}{0.4\text{kg}}$

or $a_x = -1.5\text{m/s}^2$ and $a_y = 2.5\text{m/s}^2$

Forces

Newton's 2nd Law

$$a_x = -1.5\text{m/s}^2 \;,\; a_y = 2.5\text{m/s}^2$$

Horizontal:

$$x = x_0 + v_{x,0}t + \frac{1}{2}a_x t^2 = \frac{1}{2}(-1.5\text{m/s}^2)(1.6\text{s})^2 = -1.92\text{m}$$

($x_0 \rightarrow 0$, $v_{x,0} \rightarrow 0$)

$$v_x = v_{x,0} + a_x t = (-1.5\text{m/s}^2)(1.6\text{s}) = -2.40\text{m/s}$$

($v_{x,0} \rightarrow 0$)

Vertical:

$$y = y_0 + v_{y,0}t + \frac{1}{2}a_y t^2 = \frac{1}{2}(2.5\text{m/s}^2)(1.6\text{s})^2 = 3.20\text{m}$$

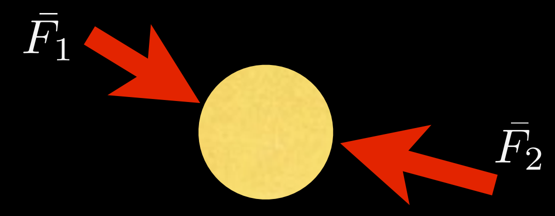
($y_0 \rightarrow 0$, $v_{y,0} \rightarrow 0$)

$$v_y = v_{y,0} + a_y t = (2.5\text{m/s}^2)(1.6\text{s}) = 4.00\text{m/s}$$

($v_{y,0} \rightarrow 0$)

Forces

Newton's 2nd Law



Position: $-1.92\bar{i} + 3.20\bar{j} \quad \text{m}$

Velocity: $\bar{v} = -2.40\bar{i} + 4.00\bar{j} \quad \text{m/s}$

Forces

Newton's 3rd Law

"If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A"

Forces come in pairs:

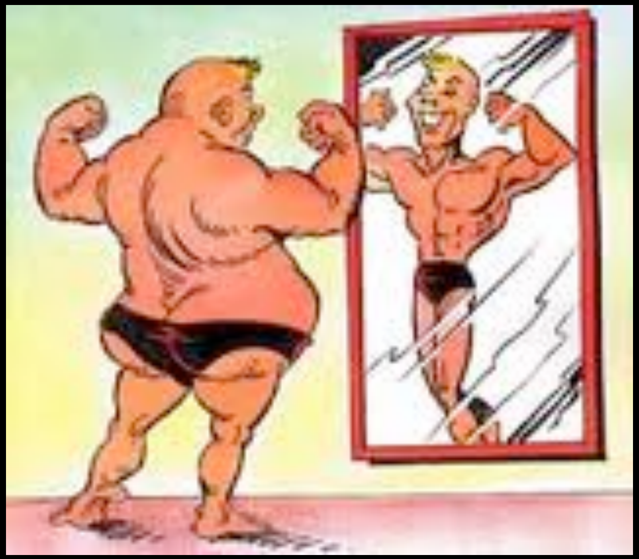
If I push you with a force F, then I feel a force F on me

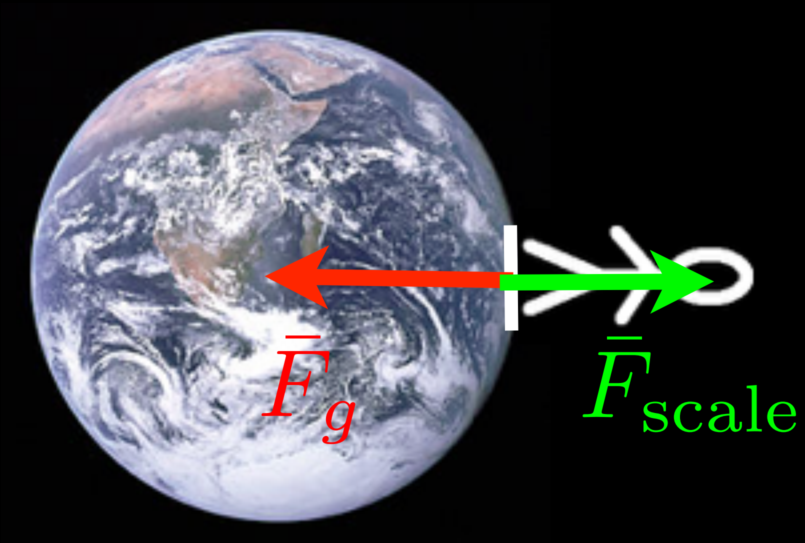
If you kick a bowling ball, it hurts!

Newton's 3rd Law

Strange but true (and sad...!)

You weigh more than you think





Gravity pulls you down

But when you stand on the scales, they exert an upwards force on you.

$$\bar{F}_{\text{net}} = \bar{F}_g + \bar{F}_{\text{scale}}$$

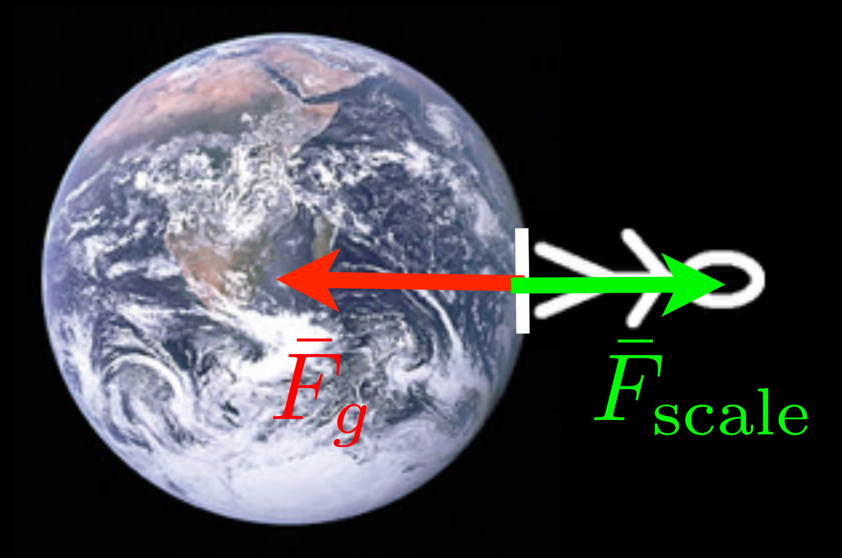
weight

"the normal force", $\bar{n}$

Forces

How different is your weight?

$$\frac{\bar{F}_g}{\bar{F}_{\mathrm{scale}}} = ?$$



$$\bar{F}_{\mathrm{net}} = \bar{F}_g + \bar{F}_{\mathrm{scale}}$$

Newton's 2nd law: $\bar{F}_{\mathrm{net}} = m\bar{a}$

Circular motion: $a = \frac{v^2}{r}$

Gravitational force: $\bar{F}_g = -mg$

$g = 9.81\mathrm{m/s}^2$

Earth's radius: $R_E = 6.37 \times 10^6\mathrm{m}$

1 orbit = 1 day

Is the answer closest to:

(a) 10 %   (b) 1 %   (c) 0.1 %   (d) 0.01 %

Forces

How different is your weight?

$$\frac{\bar{F}_g}{\bar{F}_{\text{scale}}} = \,?$$

$$\bar{F}_{\text{net}} = \bar{F}_g + \bar{F}_{\text{scale}}$$

$$\bar{F}_g \rightarrow -mg$$

$$\bar{F}_{\text{net}} = m\bar{a} = -m\frac{v^2}{r}$$

$$\rightarrow \quad \bar{F}_{\text{scale}} = mg - m\frac{v^2}{r}$$

$$v = \frac{\text{distance}}{\text{time}} = \frac{2\pi r}{24 \times 3600\,\text{s}}$$

$$\bar{F}_{\text{scale}} = mg - \frac{m}{r}\left(\frac{2\pi r}{24 \times 3600\,\text{s}}\right)^2 = mg - mr\left(\frac{2\pi}{24 \times 3600\,\text{s}}\right)^2$$

Forces

How different is your weight? $\dfrac{\bar{F}_g}{\bar{F}_{\text{scale}}} = \ ?$

$$\frac{\bar{F}_g}{\bar{F}_{\text{scale}}} = \frac{mg}{mg - mr\left(\frac{2\pi}{24\times 3600\,\text{s}}\right)^2} = 0.0034 = 0.34\%$$

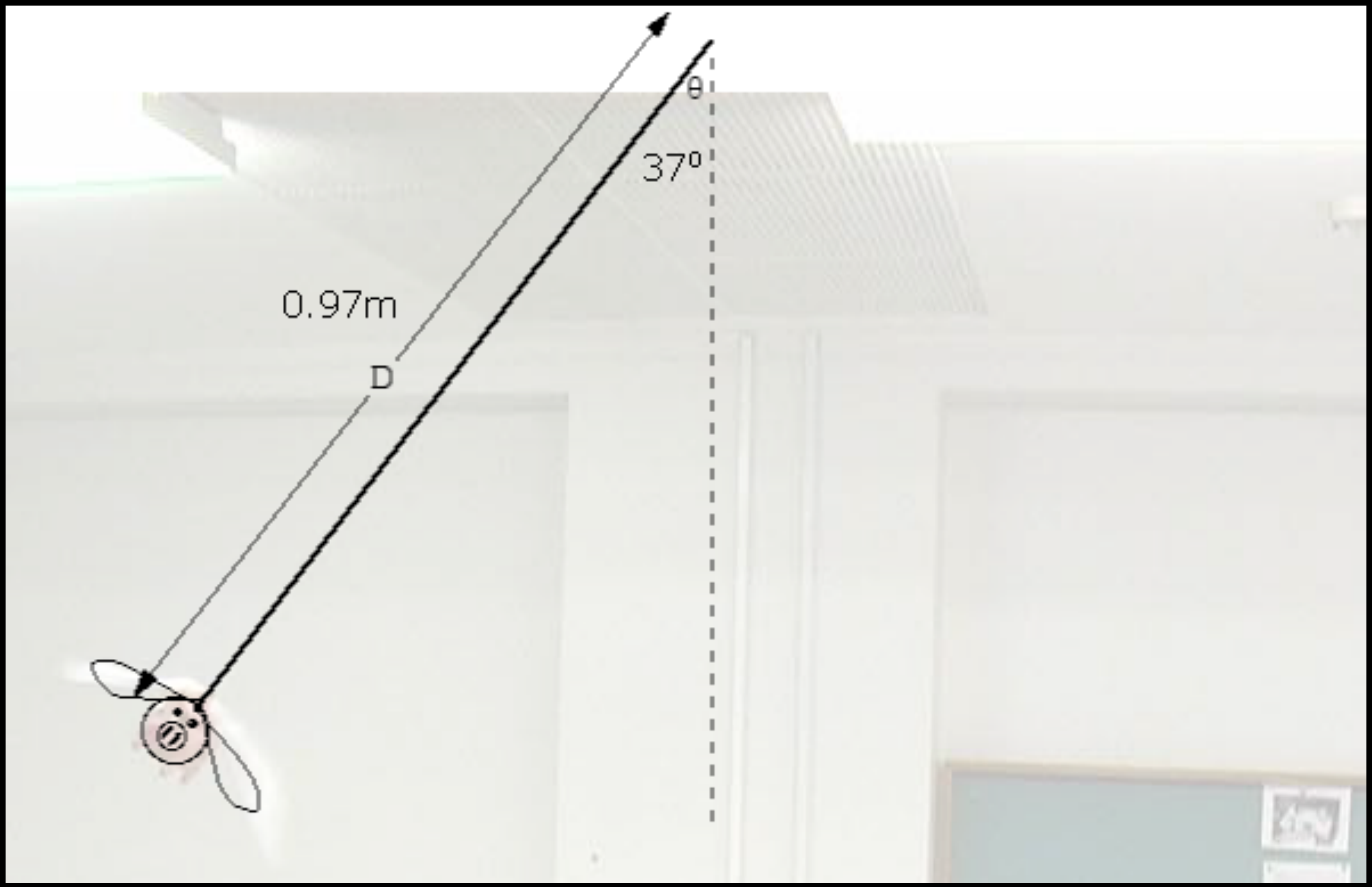
Forces + Circular Motion

The flying pig (conical pendulum)

What is the time for one orbit?

Forces + Circular Motion

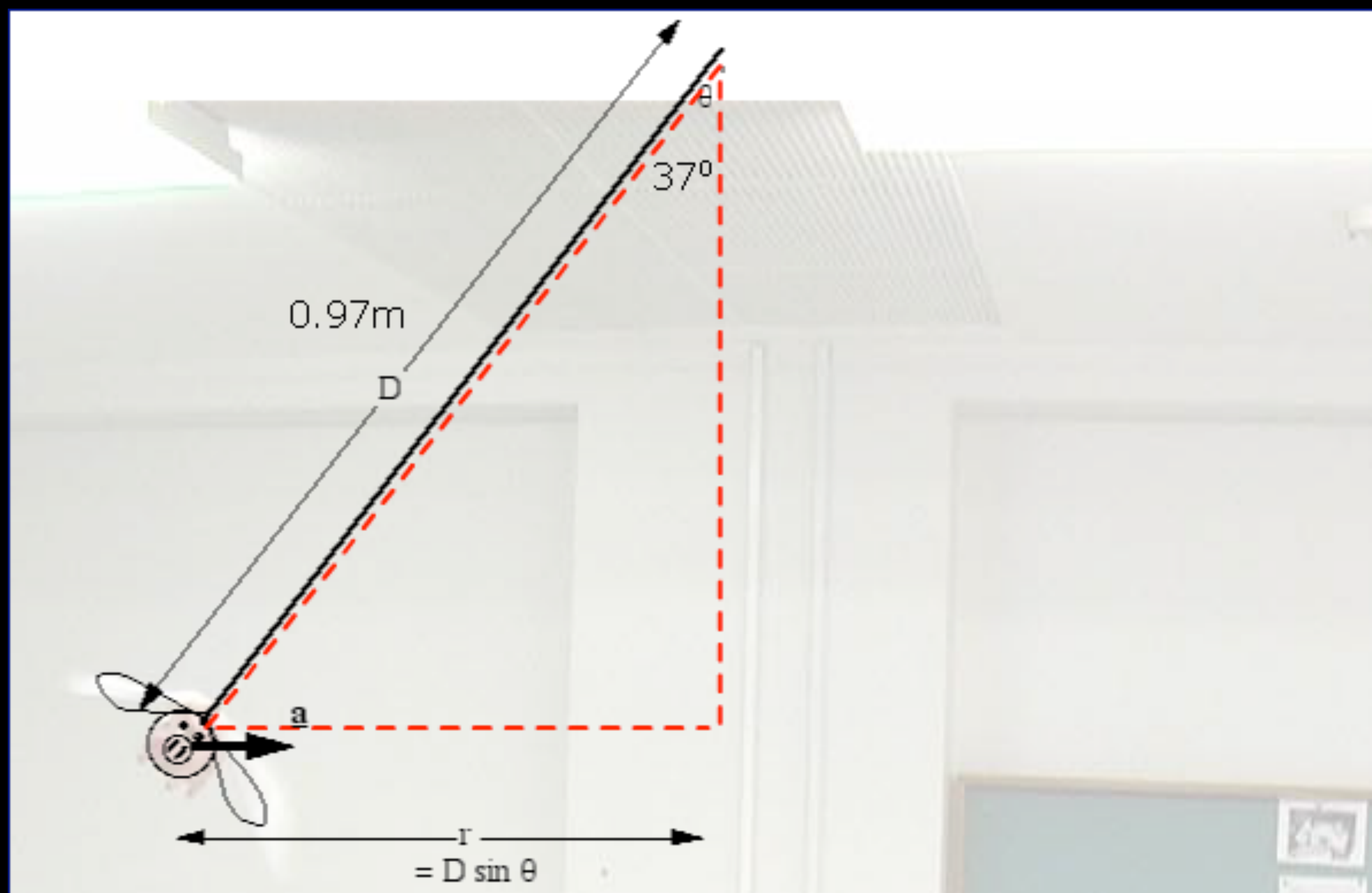
The flying pig (conical pendulum)



What is the time for one orbit?

Forces + Circular Motion

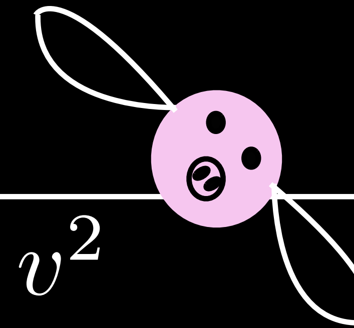
What do we know?

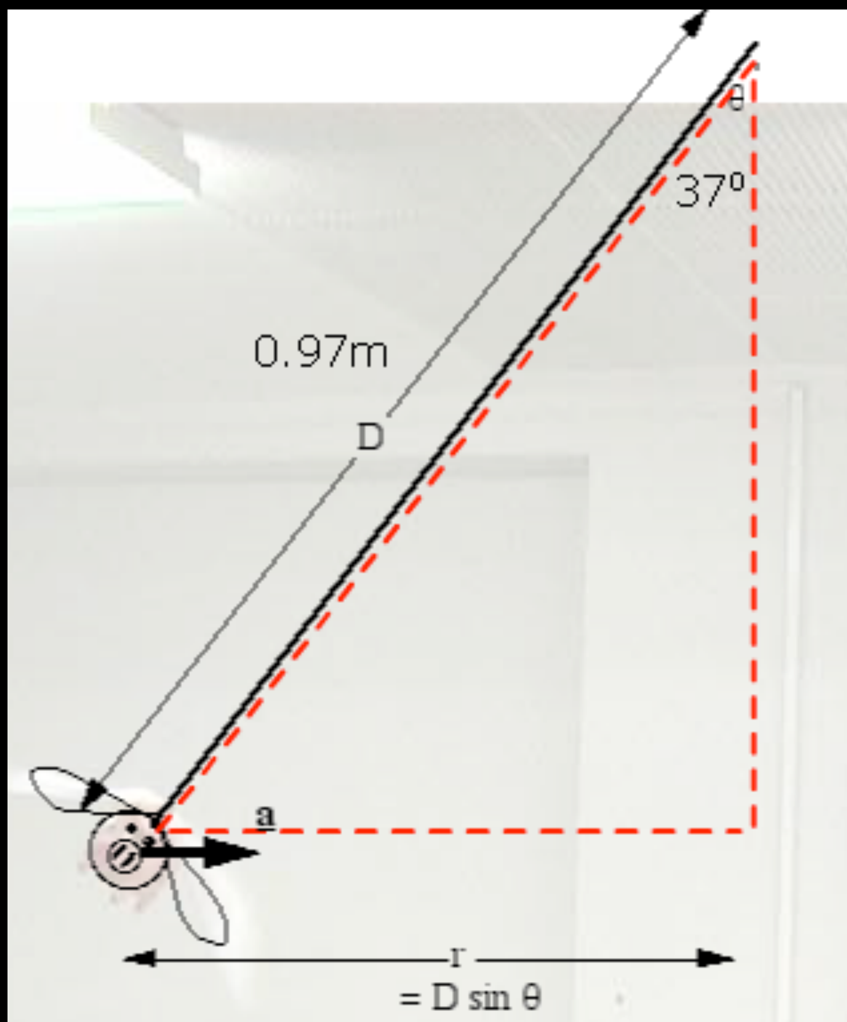


Motion is horizontal, so no net vertical acceleration: $a_{\mathrm{y,net}} = 0$

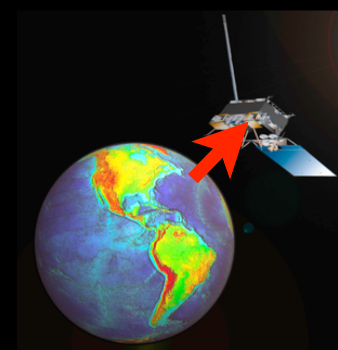
But there is centripetal acceleration: $a_{\mathrm{x,net}} = \bar{a}_c$

Forces + Circular Motion



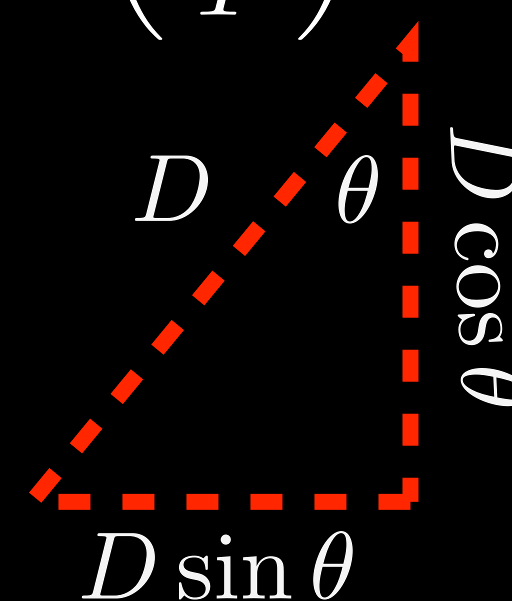


Circular motion: $a_{\text{x,net}} = \bar{a}_c = \dfrac{v^2}{r}$



$$\longrightarrow \quad v = \frac{2\pi r}{T}$$

$$a_{\text{x,net}} = r\left(\frac{2\pi}{T}\right)^2 \quad = D\sin\theta\left(\frac{2\pi}{T}\right)^2$$

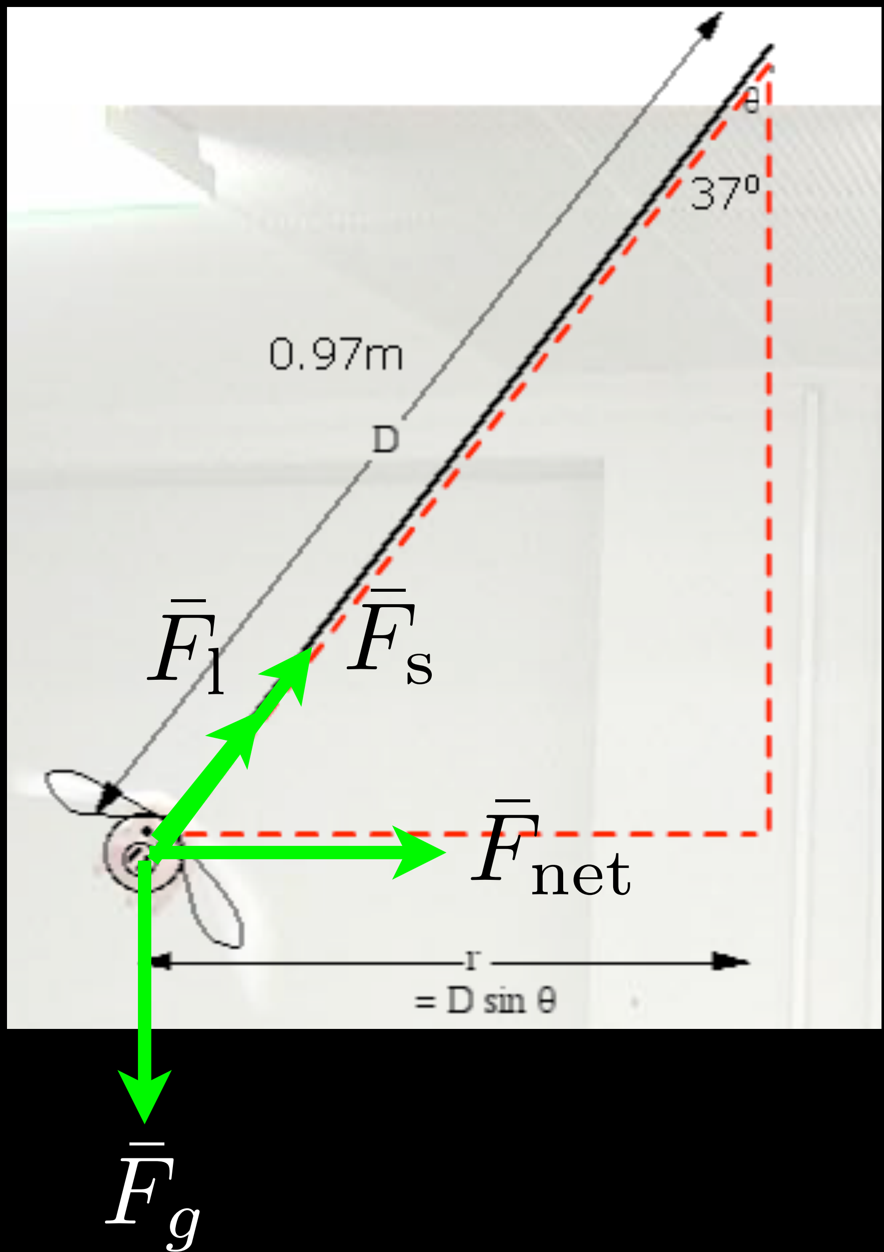


Therefore: $T = 2\pi\sqrt{\dfrac{D\sin\theta}{a_{\text{x,net}}}}$

So, if we know $a_{\text{x,net}}$ we'd have the period.

Let's look at Newton's 2nd law....

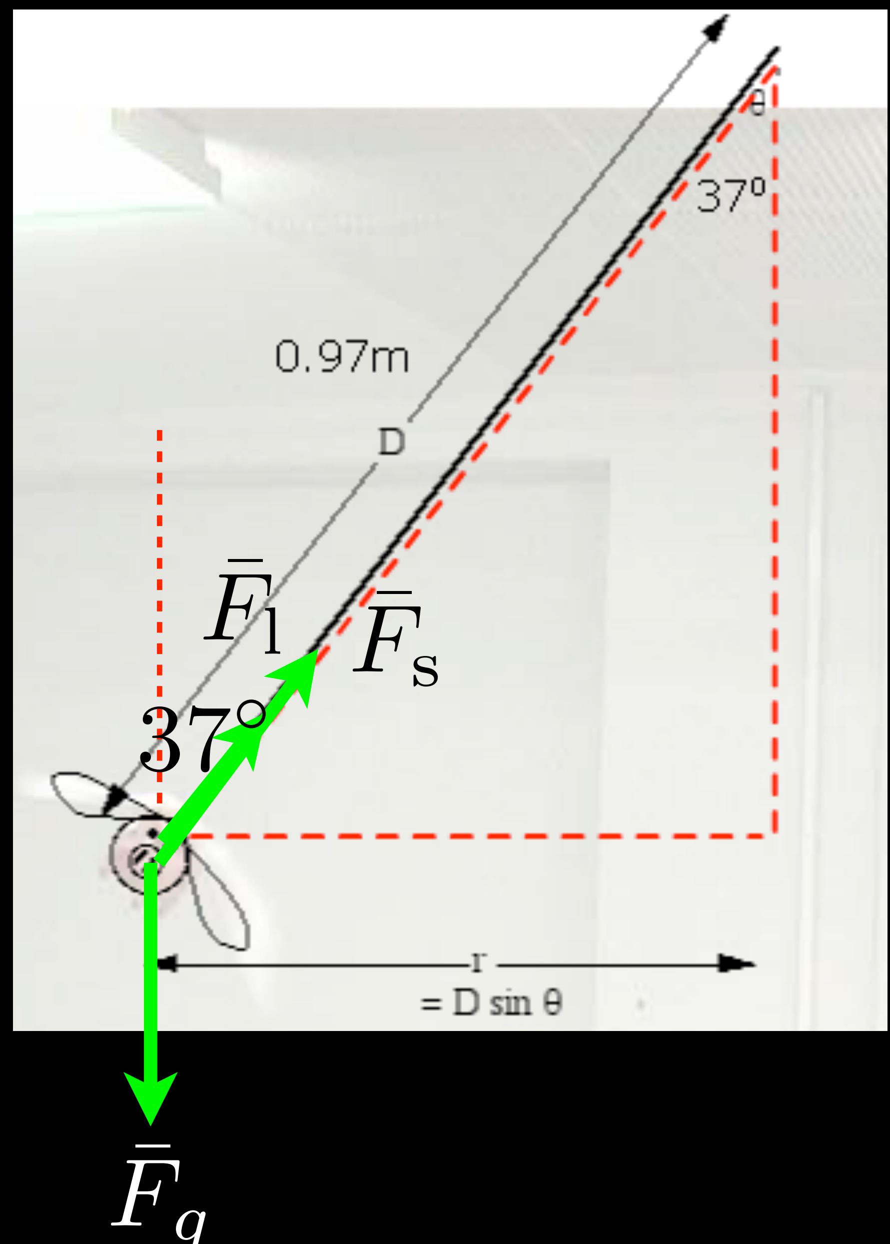
Forces + Circular Motion



Forces	
Net force (same direction as acceleration)	$\bar{F}_{\rm net}$
Gravity	$\bar{F}_g$
String	$\bar{F}_{\rm s}$
Wing lift	$\bar{F}_{\rm l}$

Since force is a vector, we can look at each component

Forces + Circular Motion



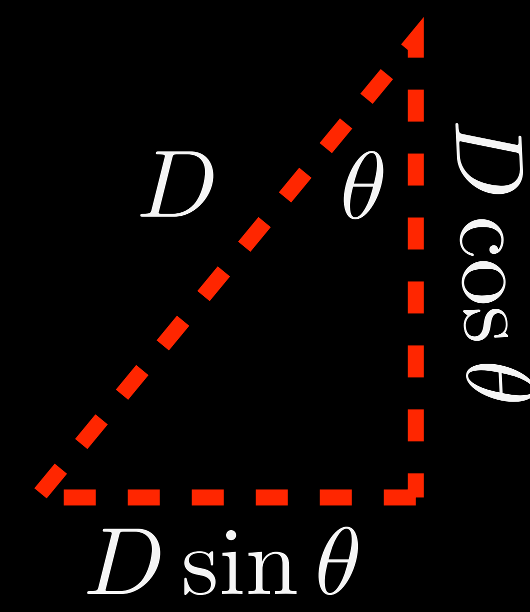
horizontal $\bar{F} = m\bar{a}$

net force = $(F_s + F_l)\sin\theta = m a_{x,net}$

vertical $\bar{F} = m\bar{a}$

$$(F_s + F_l)\cos\theta - F_g = 0$$

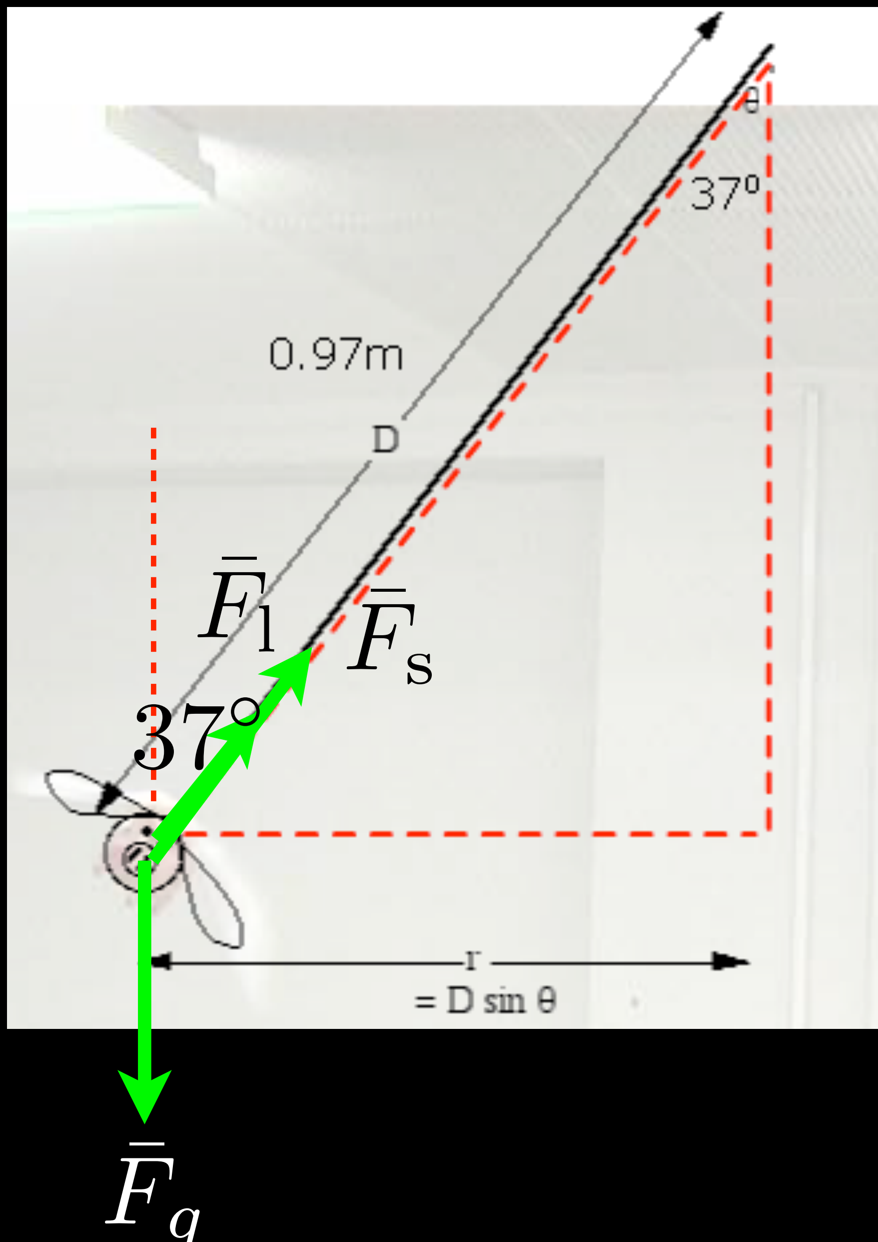
$$(F_s + F_l) = \frac{F_g}{\cos\theta}$$



$$F_g \frac{\sin\theta}{\cos\theta} = m a_{x,net} \longrightarrow a_{x,net} = \frac{F_g \tan\theta}{m} = g\tan\theta$$

$$F_g = mg$$

Forces + Circular Motion



From:

$$T = 2\pi\sqrt{\frac{D\sin\theta}{a_{\mathrm{x,net}}}}$$

$$a_{\mathrm{x,net}} = g\tan\theta$$

$$T = 2\pi\sqrt{\frac{D\cos\theta}{g}}$$

$$= 2\pi\sqrt{\frac{0.97\mathrm{m}\cos 37^\circ}{9.81\mathrm{m/s^2}}} = 1.8\mathrm{s}$$

Problem solving

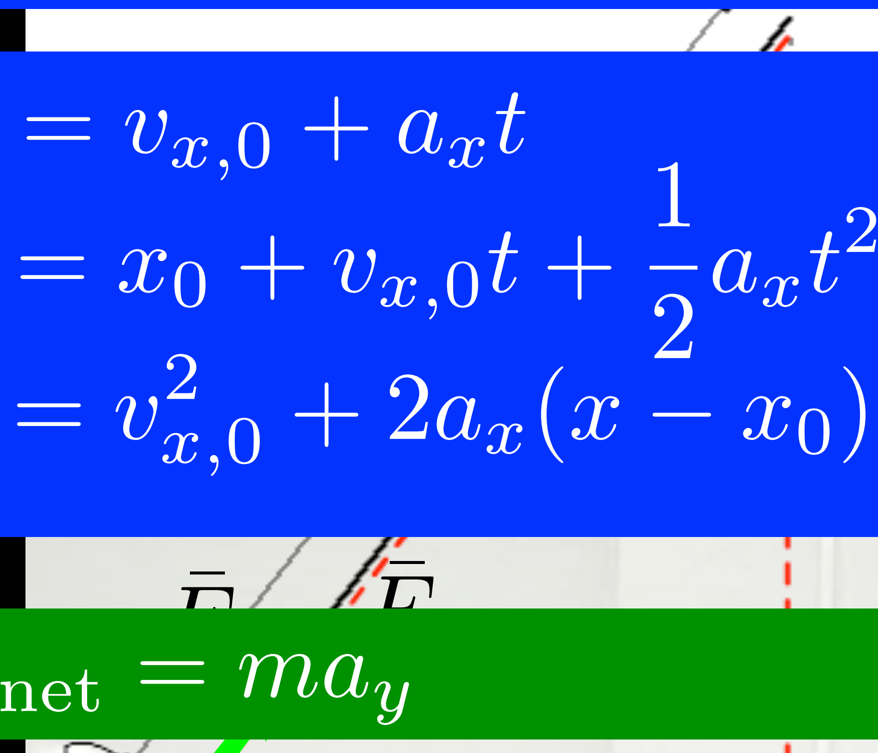
(1) Draw a diagram

(2) Balance the forces

(3) Consider each component

(4) Get full marks

$$F_{\mathrm{x,net}} = ma_x$$



$$v_x = v_{x,0} + a_x t$$
$$x = x_0 + v_{x,0}t + \frac{1}{2}a_x t^2$$
$$v_x^2 = v_{x,0}^2 + 2a_x(x - x_0)$$

$$F_{\mathrm{y,net}} = ma_y$$

$$v_y = v_{y,0} + a_y t$$
$$y = y_0 + v_{y,0}t + \frac{1}{2}a_y t^2$$
$$v_y^2 = v_{y,0}^2 + 2a_y(y - y_0)$$

$$a = \frac{v^2}{r}$$

Problem solving

A 2 kg picture is hung by 2 wires of equal length.

Each makes an angle $\theta = 30^\circ$ with the horizontal.

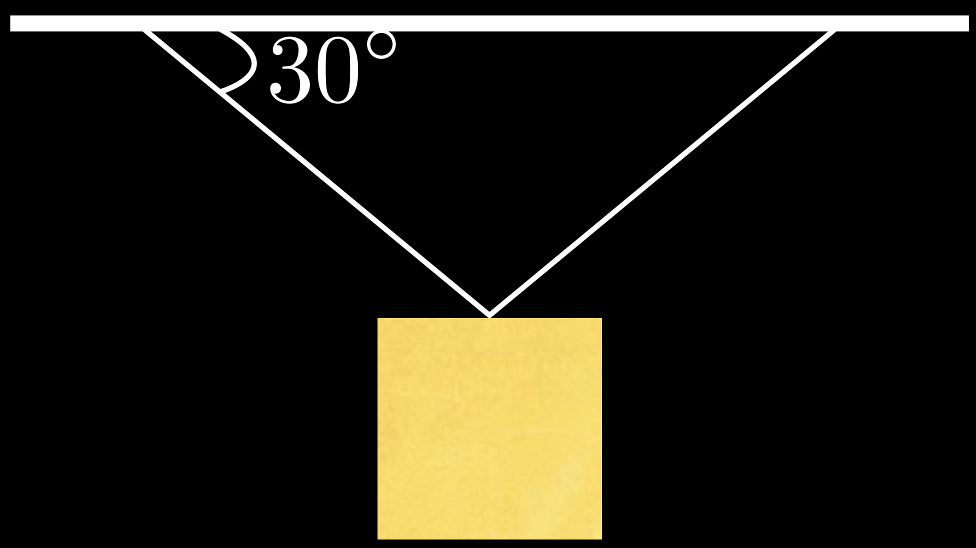
Find the tension in the wires.

(a) 0N

(b) 9.81N

(c) 39.21N

(d) 19.62N



Problem solving

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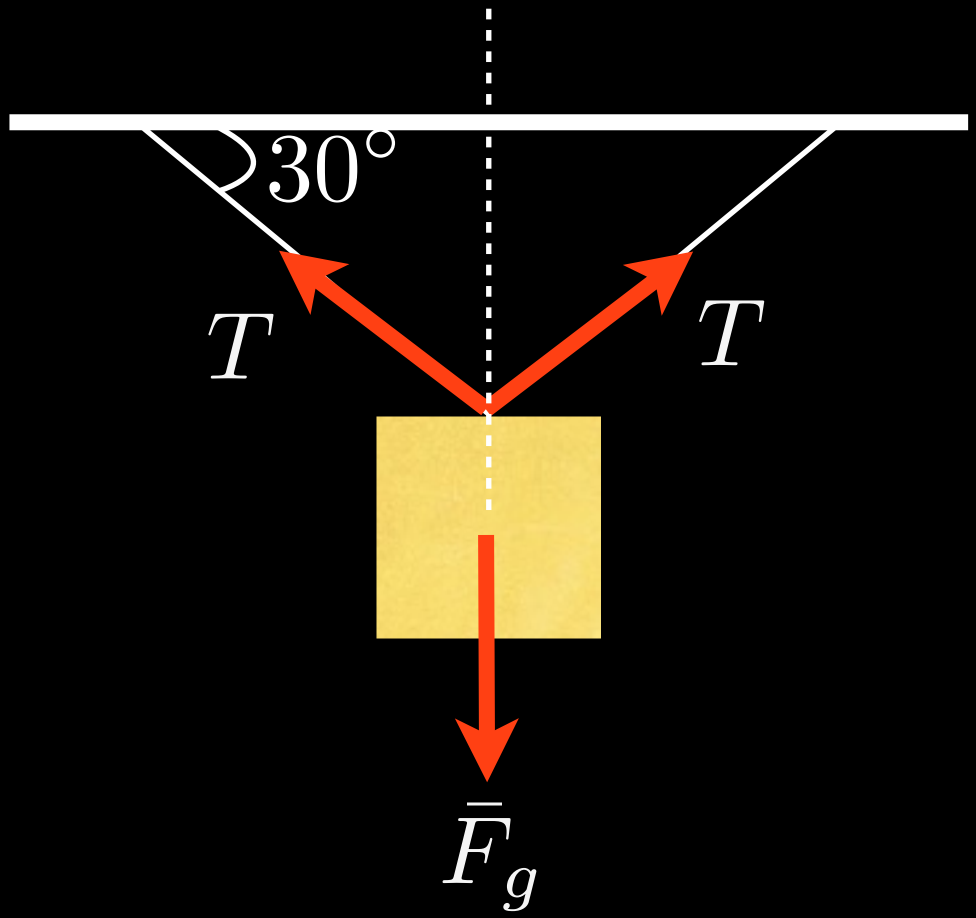


vertical $\quad \bar{F} = m\bar{a}$

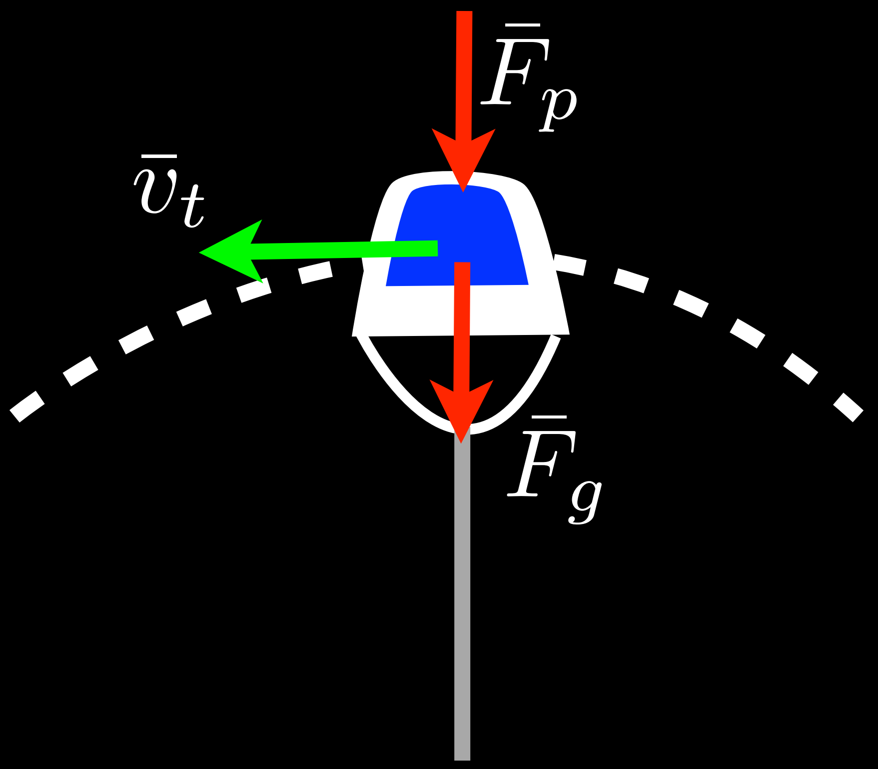
$$F_g = T\sin\theta + T\sin\theta = mg$$

$$T = \frac{mg}{2\sin 30^\circ} = \frac{2\,\text{kg} \times 9.81\,\text{m/s}^2}{2\sin 30^\circ}$$

$$= 19.62\,\text{N}$$

Forces + Circular Motion quiz

A bucket of water is whirled in a vertical circle of radius, r.

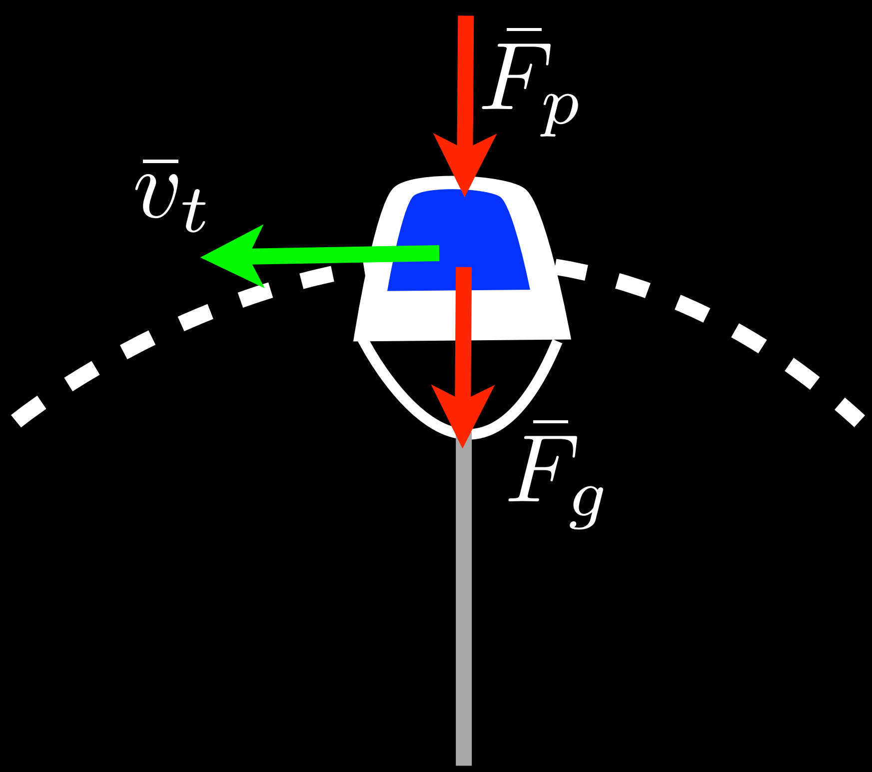


Forces + Circular Motion quiz

A bucket of water is whirled in a vertical circle of radius, r.

If its speed is v_t at the top of the circle, find the force (as an expression)exerted on the water, $\bar{F}_p$, by the bucket at the top of the circle.

If $r = 1m$, what is the minimum v_t for which the water will remain in the bucket?



$$\bar{F}_p = ?$$

$$\bar{v}_{t,\min} = ?$$

Forces + Circular Motion

quiz

A bucket of water is whirled in a vertical circle of radius, r.

If its speed is v_t at the top of the circle, find the force (as an expression)exerted on the water, $\bar{F}_p$, by the bucket at the top of the circle.

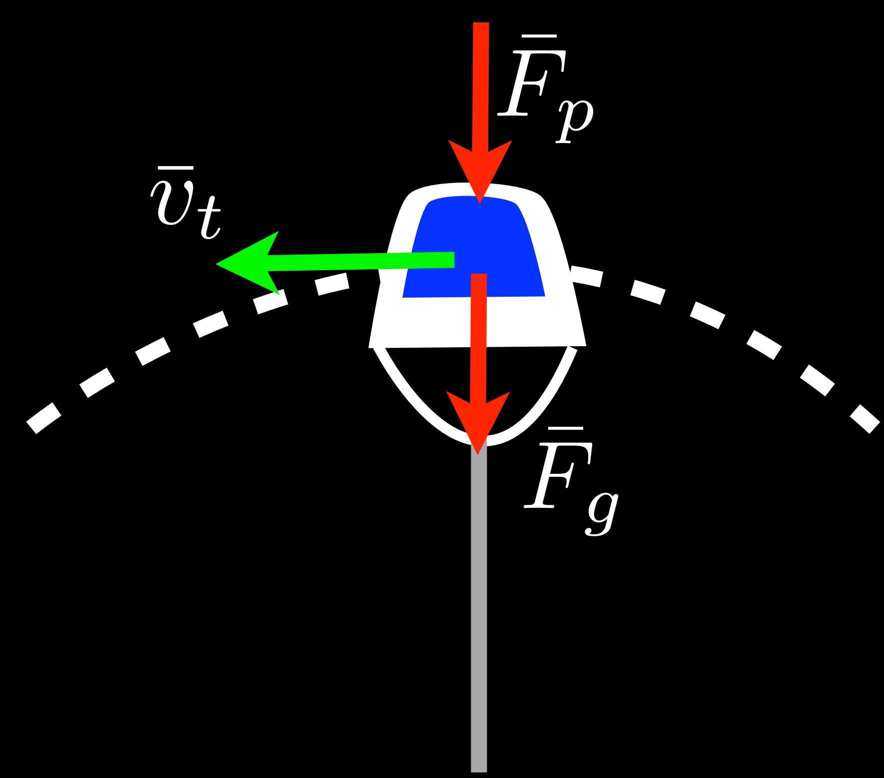
If $r = 1m$, what is the minimum v_t for which the water will remain in the bucket?

(a) $\bar{v}_{t,\mathrm{min}} = 6.21\mathrm{m/s}$

(b) $\bar{v}_{t,\mathrm{min}} = 5.4\mathrm{m/s}$

(c) $\bar{v}_{t,\mathrm{min}} = 1.24\mathrm{m/s}$

(d) $\bar{v}_{t,\mathrm{min}} = 3.13\mathrm{m/s}$



Forces + Circular Motion

quiz

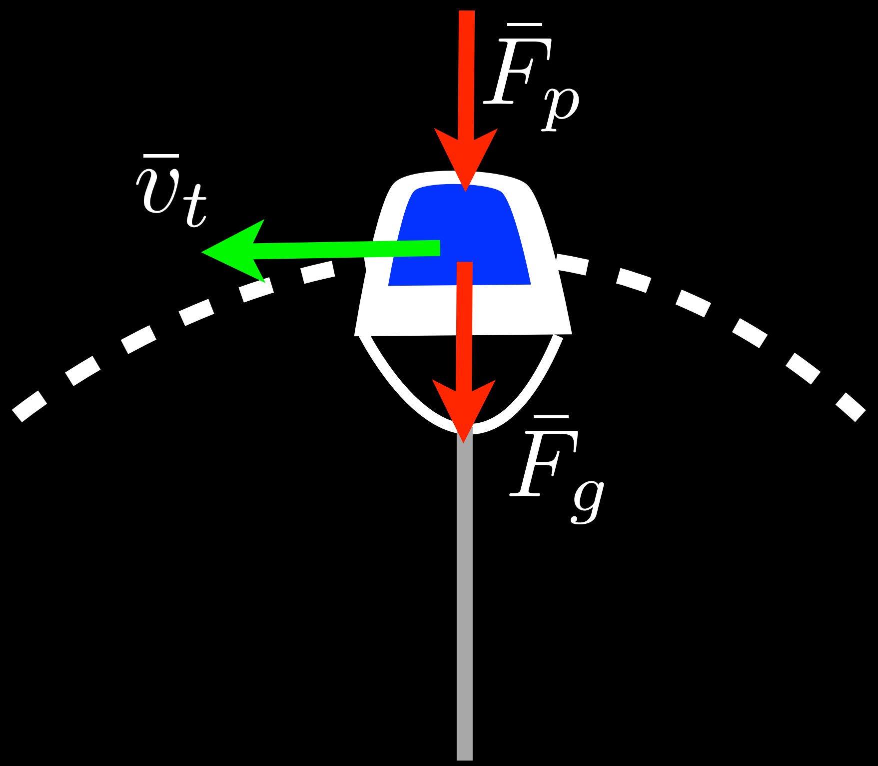
vertical $\bar{F} = m\bar{a}$

$$F_p + F_g = m\frac{v_t^2}{r}$$

mg

$$F_p = m\frac{v_t^2}{r} - mg$$

mg → constant



If v_t ↑ F_p ↑ If v_t ↓ F_p ↓

Since F_p cannot exert upwards force on the bucket, minimum OK speed at top is when $F_p = 0$.

$$mg = m\frac{v_{t,\text{min}}^2}{r}$$

$$v_{\text{t,min}} = \sqrt{rg} = \sqrt{1\,\text{m} \times 9.81\,\text{m}} = 3.13\,\text{m/s}$$

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16 March 2012 Last updated at 12:53 GMT

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Skydiver Felix Baumgartner on track for super jump

By Jonathan Amos
Science correspondent

Motion in 1D

Constant acceleration

What to look for

WHAT was discovered?

HOW was it done?

WHY is it exciting?

Skydive

WHAT

Skydive from 71,500 ft

Austrian skydiver Felix Baumgartner is well on the way to setting a world record for the highest free-fall jump.

On Thursday, the adventurer leapt from a balloon-borne capsule 71,500ft (22km) above New Mexico, landing safely eight minutes later.

The dive was intended to test all his equipment before he tries to free-fall from 120,000ft later this year.

In doing so, he would better the mark of 102,800ft set by US Air Force Colonel Joe Kittinger in 1960.

Even just Thursday's jump puts Baumgartner in a select group as only Kittinger and Russian Eugene Andreev have descended from higher.

Baumgartner, who is famous for stunts such as jumping off the Petronas Towers, is seen in the special pressure suit he must wear to stay alive in the thin air and extreme cold of the stratosphere.

Skydive

WHY

Practice for world record skydive

Already #3 in the world

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Skydive

HOW

His **Red Bull Stratos** team estimates he reached 364mph (586km/h) during the descent, and was in free fall for three minutes and 43 seconds before opening his parachute. From capsule to ground, the entire jump lasted eight minutes and eight seconds.

8 minute 8 second jump with top speed, 364 mph.

Skydive

> The 42-year-old was quoted afterwards as saying that the cold was hard to handle.
>
> "I could hardly move my hands. We're going to have to do some work on that aspect," he said.
>
> The Austrian also said the extraordinary dimensions of the high atmosphere took some getting used to: "I wanted to open the parachute after descending for a while but I noticed that I was still at an altitude of 50,000ft."

Not easy!

Cold may still be a problem on the big jump

Skydive

Summary

Skydiver Felix Baumgartner jumped from 71,500 ft.

WHAT

This was a practice for a world record attempt.

WHY

This jump was the 3rd highest ever attempted.

The jump lasted 8 minute 8 seconds with a top speed of 364 mph.

HOW

Skydive

quiz

His **Red Bull Stratos** team estimates he reached 364mph (586km/h) during the descent, and was in free fall for three minutes and 43 seconds before opening his parachute. From capsule to ground, the entire jump lasted eight minutes and eight seconds.

Estimate the acceleration

(a) $a = 170\,\mathrm{m/s^2}$

(b) $a = 9.81\,\mathrm{m/s^2}$

(c) $a = 2.63\,\mathrm{m/s^2}$

(d) $a = 0.73\,\mathrm{m/s^2}$

Skydive

quiz

His **Red Bull Stratos** team estimates he reached 364mph (586km/h) during the descent, and was in free fall for three minutes and 43 seconds before opening his parachute. From capsule to ground, the entire jump lasted eight minutes and eight seconds.

Estimate the acceleration

$$a_{\text{average}} = \frac{\Delta v}{\Delta t}$$

$$\Delta v = 586\,\frac{\text{km}}{\text{h}} = \left(586\,\frac{\text{km}}{\text{h}}\right)\left(\frac{1000\,\text{m}}{1\,\text{km}}\right)\left(\frac{1\,\text{h}}{3600\,\text{s}}\right) = 163\,\text{m/s}$$

$$\Delta t = 3\,\text{min} + 43\,\text{s} = (3\,\text{min})\left(\frac{60\,\text{s}}{1\,\text{min}}\right) + 43\,\text{s} = 223\,\text{s}$$

$$a = \frac{163\,\text{m/s}}{223\,s} = 0.73\,\text{m/s}^2$$

Skydive

quiz

> His **Red Bull Stratos** team estimates he reached 364mph (586km/h) during the descent, and was in free fall for three minutes and 43 seconds before opening his parachute. From capsule to ground, the entire jump lasted eight minutes and eight seconds.

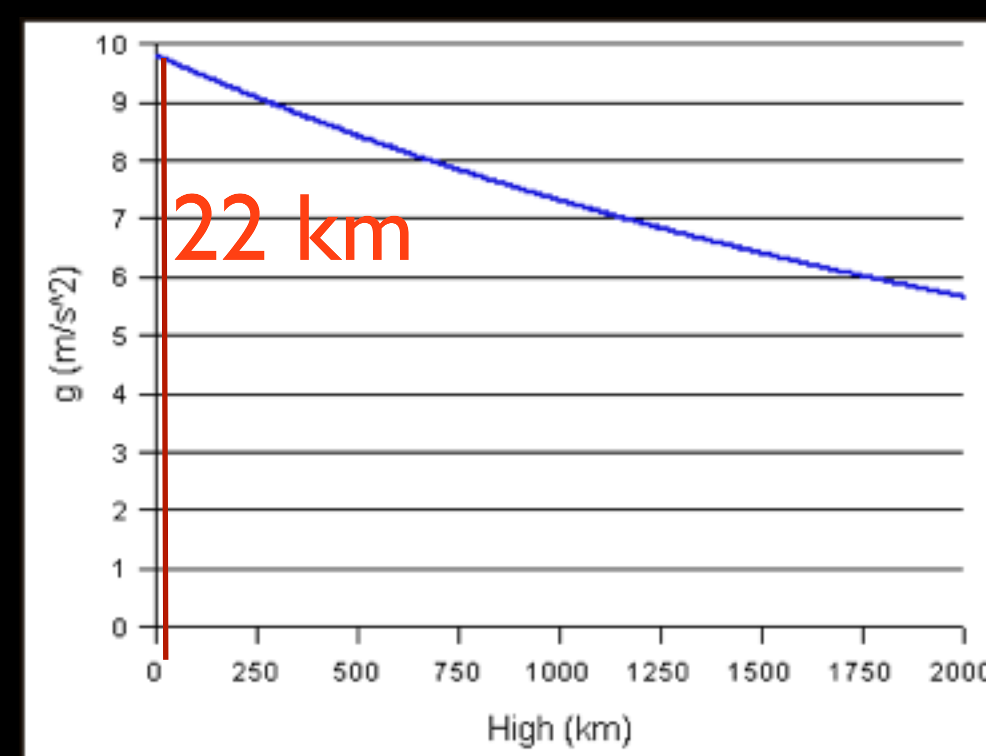
Why is $a \neq 9.81\,\mathrm{m/s^2}$?

(a) There is a mistake in this article

(b) A second force is acting

(c) Gravity is not constant so high up

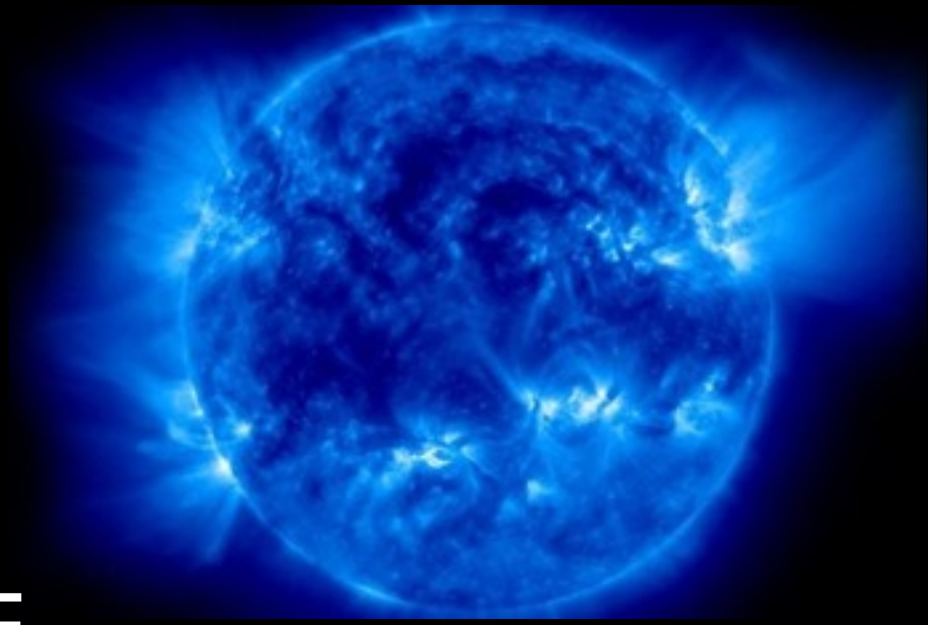
(d) Equations do not apply in real life



Skydive

quiz

When a massive star ($\sim 1.4 - 3 \ \times M_{\rm sun}$) dies, it can leave a neutron star.



$\sim$ 10 km

Neutron stars are massive but tiny!

Gravitational acceleration is therefore HUGE

$$g_{\rm neutron} \sim 10^{12}\,{\rm m/s^2}$$

If Felix jumped from 22 km above the surface of a neutron star, how long until he hit the star?

(a) 1 day (b) 1 minute (c) 1 second (d) 1 millisecond

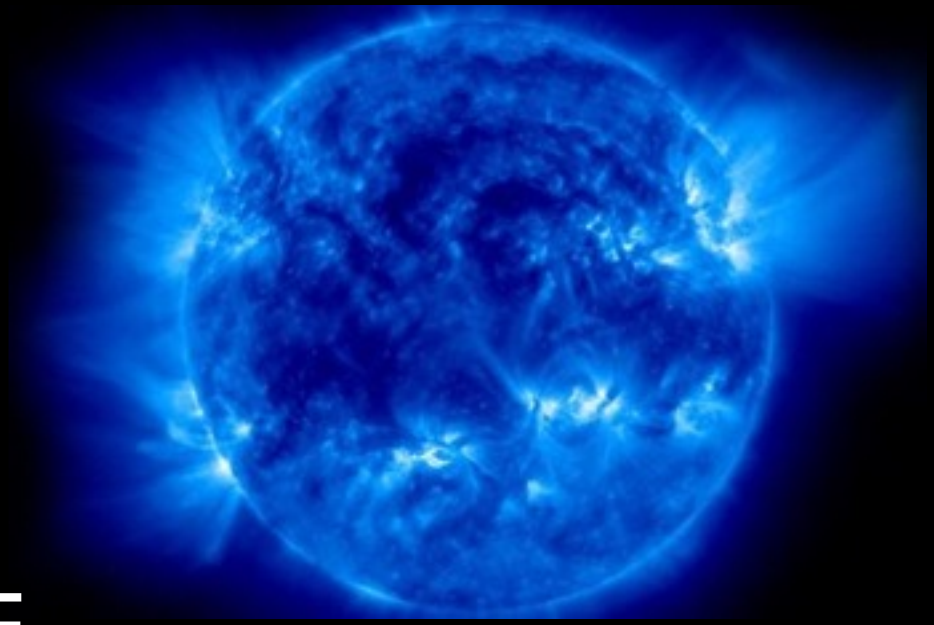
(e) 0.1 millisecond (f) 0.01 millisecond

Skydive

quiz

When a massive star ($\sim 1.4 - 3 \times M_{\text{sun}}$) dies, it can leave a neutron star.

Neutron stars are massive but tiny!



$\sim$ 10 km

Gravitational acceleration is therefore HUGE

$$g_{\text{neutron}} \sim 10^{12}\,\text{m/s}^2$$

$$y = y_0 + v_{y,0}t + \frac{1}{2}a_y t^2$$

$$0 = 22,000 + 0t + \frac{1}{2}(-10^{12})t^2$$

$$t = 0.2\,\text{ms}$$

This lecture

- Understand why circular motion does not have constant acceleration
- Be able to calculate the orbit of a satellite
- Know Newton's 3 force laws
- Contradict conspiracy theories about the moon landing
- Know your real weight
- Calculate the motion of a flying pig