Essential Physics I

英語で学ぶ物理学のエッセンス I

Lecture 5: 16-05-16

Review: Forces & circular motion

Quiz

A space station's shape is a ring, 450 m in diameter.

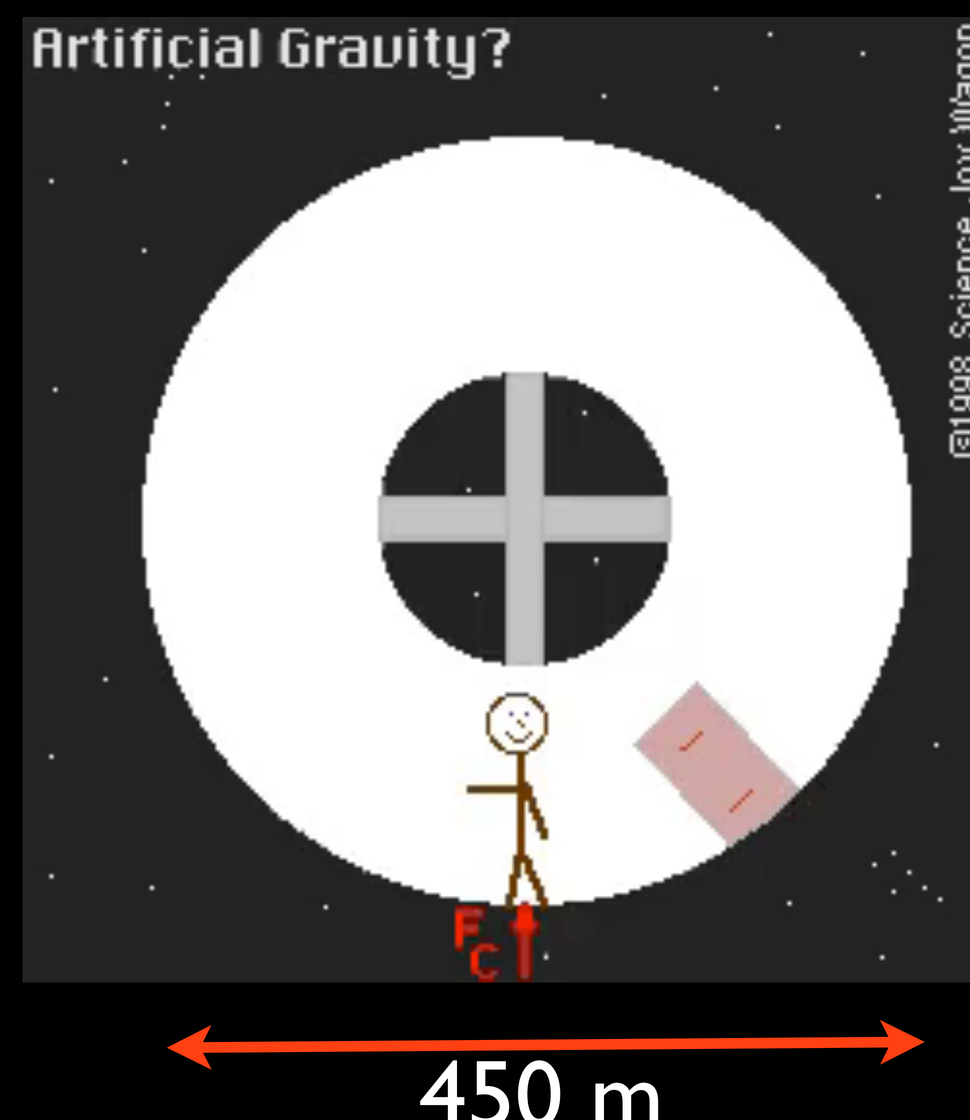
How many revolutions (turns) per minute should it rotate in order to simulate the Earth's gravity, $g = 9.81\,\mathrm{m/s^2}$?

(a) ~1.5 revs/min

(b) ~2.0 revs/min

(c) ~4.0 revs/min

(d) ~30 revs/min



Review: Forces & circular motion

Quiz

A space station's shape is a ring, 450 m in diameter.

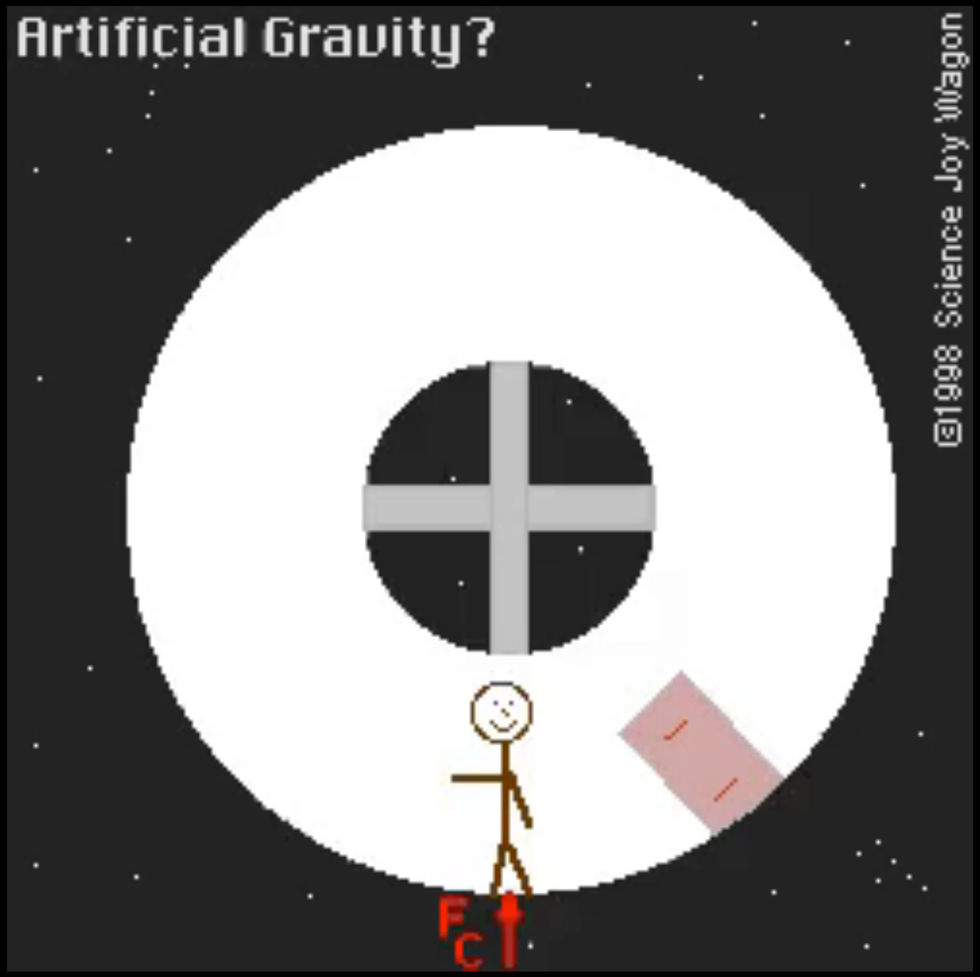
How many revolutions (turns) per minute should it rotate in order to simulate the Earth's gravity, $g = 9.81\,\mathrm{m/s^2}$?

$$a = \frac{v^2}{r} = g = 9.81$$

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

$$T = \sqrt{\frac{4\pi^2 r}{g}} = \sqrt{\frac{4\pi^2 D}{2g}} = 30.1s$$

$$\mathrm{rev/min} = 60.0/30.1 \sim 2$$



450 m

Review: Forces & circular motion

Quiz

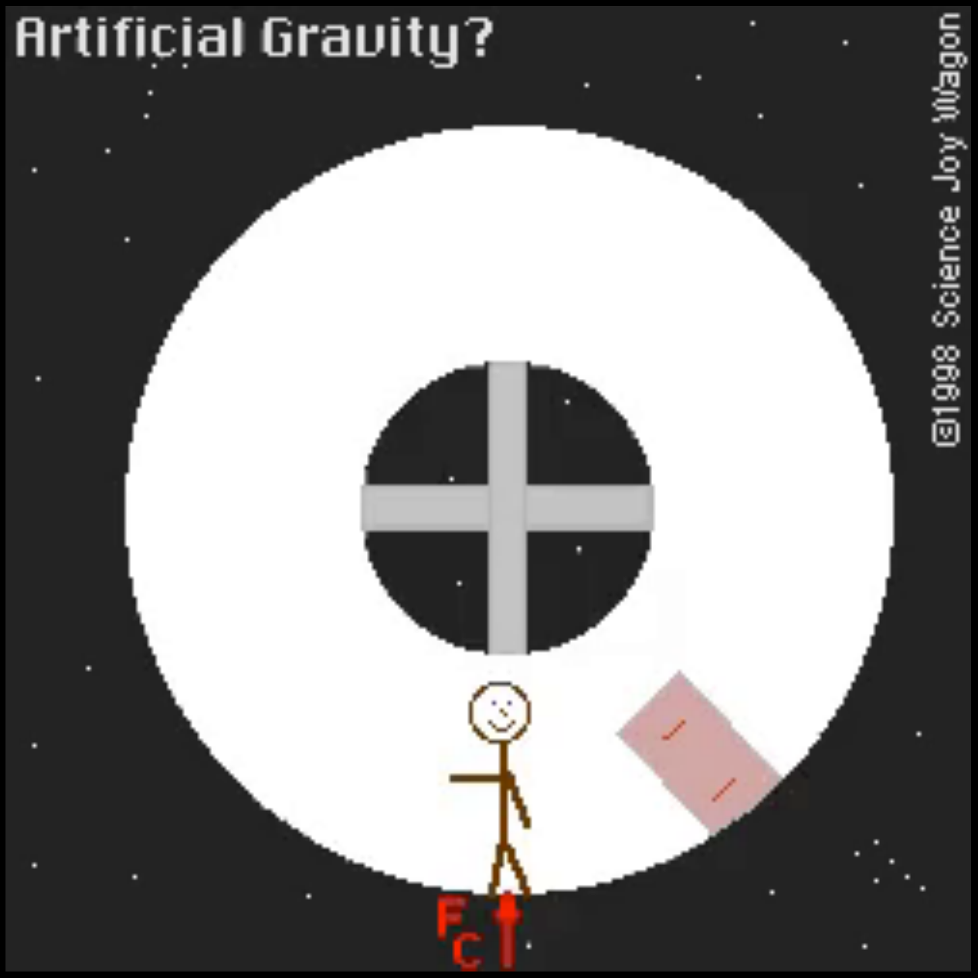
If centripetal acceleration acts towards the centre, why does the person walk on the outside edge?

(a) Bad diagram!

(b) There is another (centrifugal) force acting to balance the centripetal force

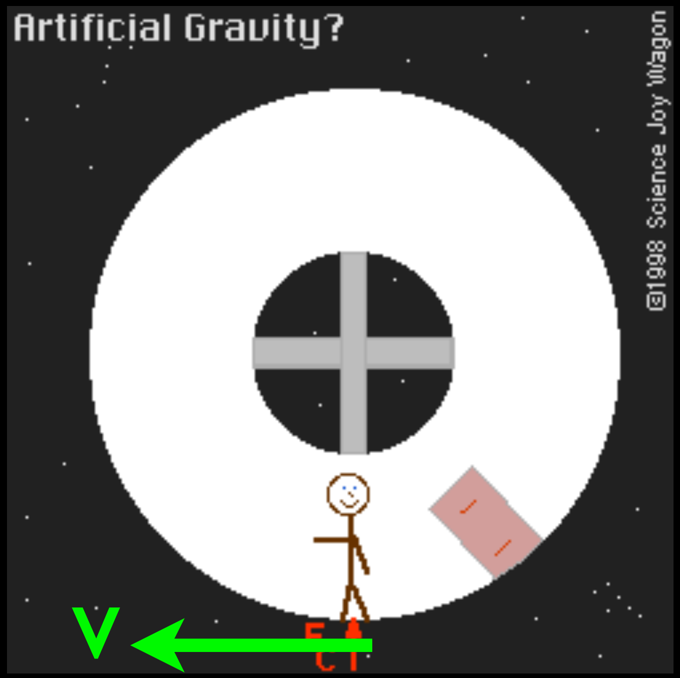
(c) Newton's laws are different on the space station

(d) there is an extra force creating artificial gravity



Review: Forces & circular motion

Quiz

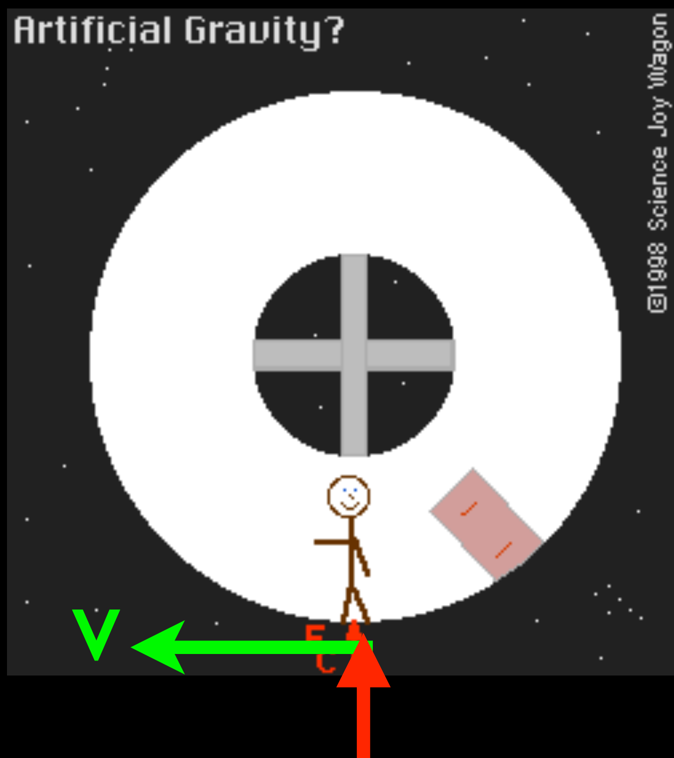


Person thinks he should walk in a straight line (Newton's 1st)

But the space station is accelerating:

Review: Forces & circular motion

Quiz

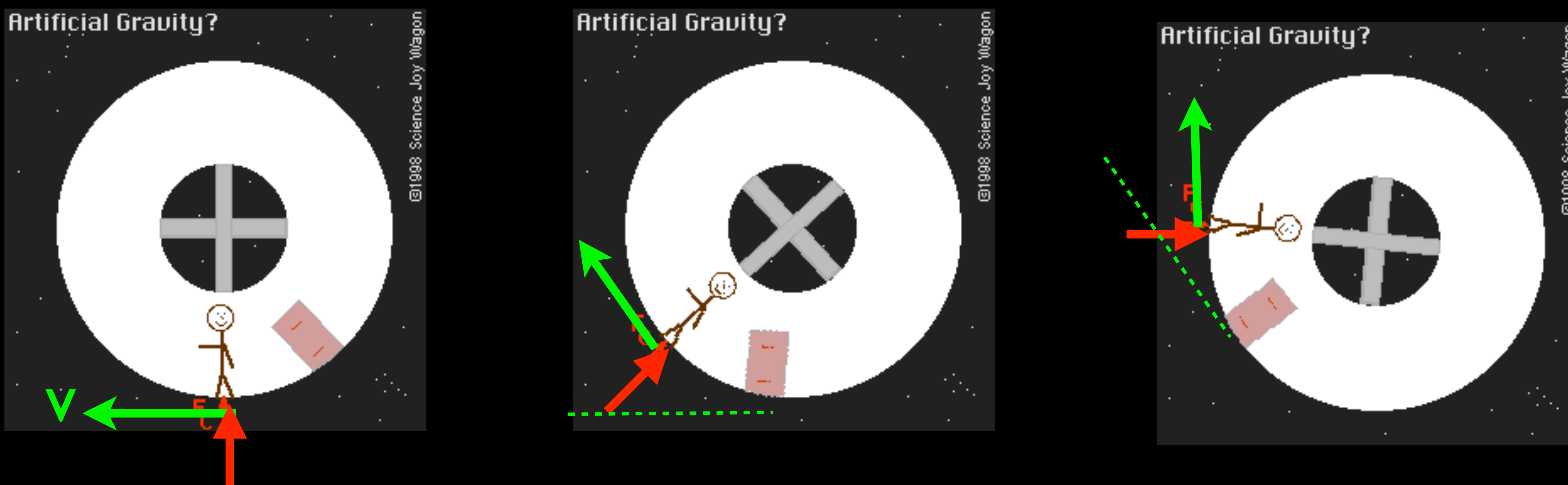


Person thinks he should walk in a straight line (Newton's 1st)

But the space station is accelerating: A force is acting

Review: Forces & circular motion

Quiz



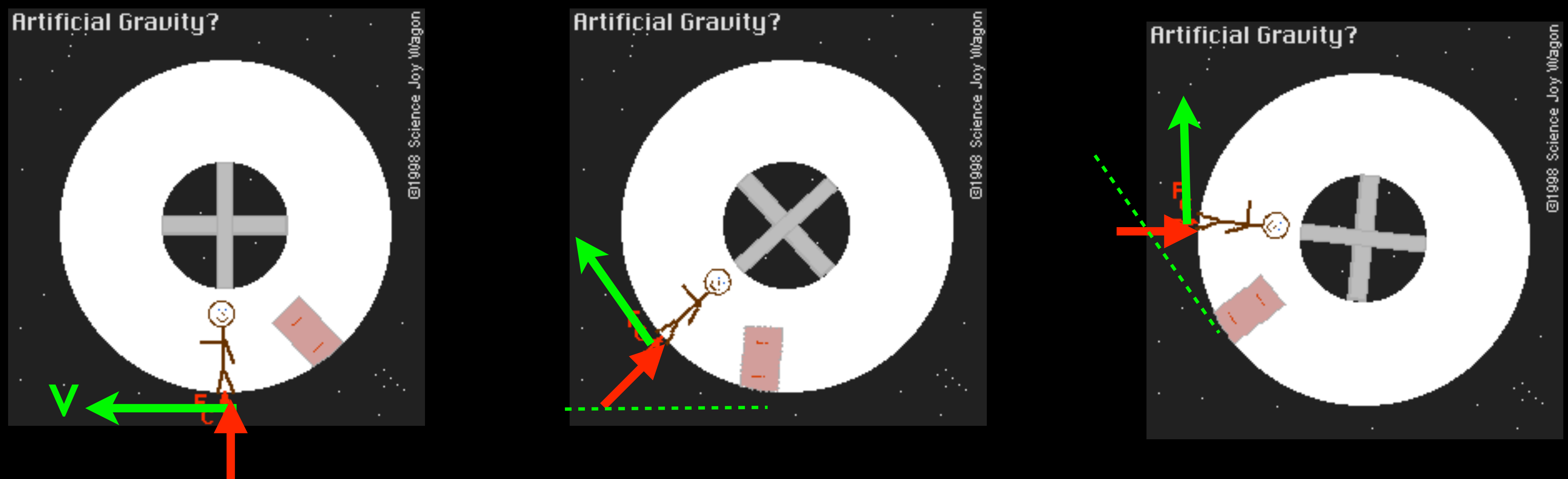
Person thinks he should walk in a straight line (Newton's 1st)

But the space station is accelerating: A force is acting

It pushes his path inwards (centripetal force)

Review: Forces & circular motion

Quiz



Person thinks he should walk in a straight line (Newton's 1st)

But the space station is accelerating: A force is acting

It pushes his path inwards (centripetal force)

But to the person, the force *seems* to push him outwards

This is called the 'centrifugal force' but it is a fake force due to this not being an inertial frame (see lecture 4)

This lecture: different forces

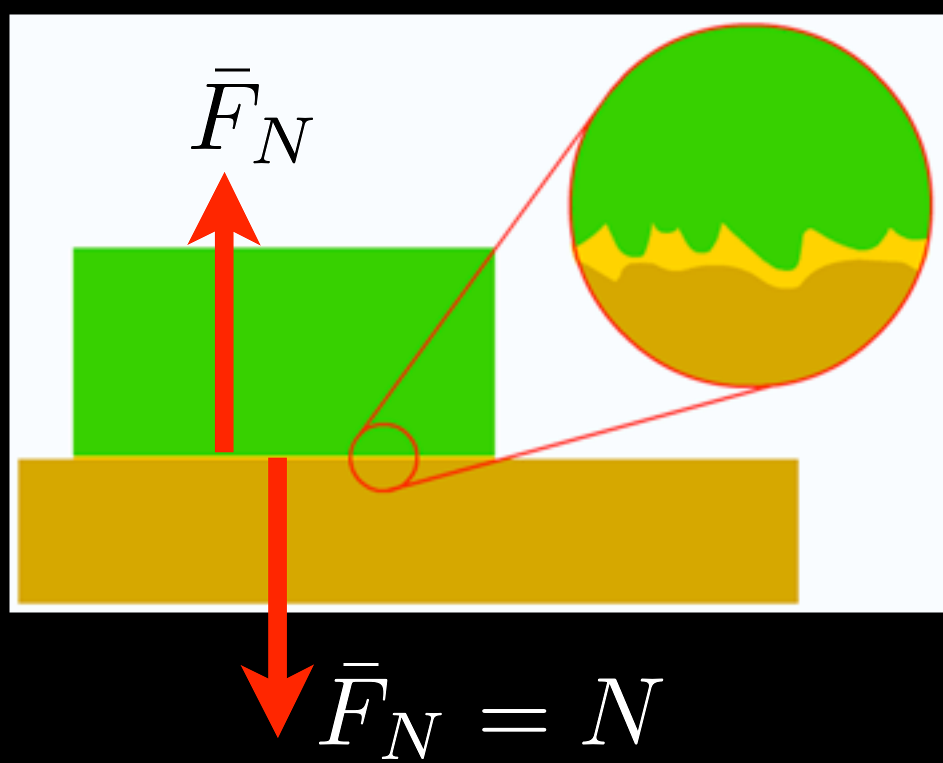
- Calculate the forces from: Friction
  Springs
  Drag
- Calculate the friction force for stationary ($v = 0$) and moving objects.
- Use Hooke's Law to calculate the force for springs
- Draw a diagram showing the forces acting on an object
- ... and calculate its motion

Friction

.... or lack of it!

Friction

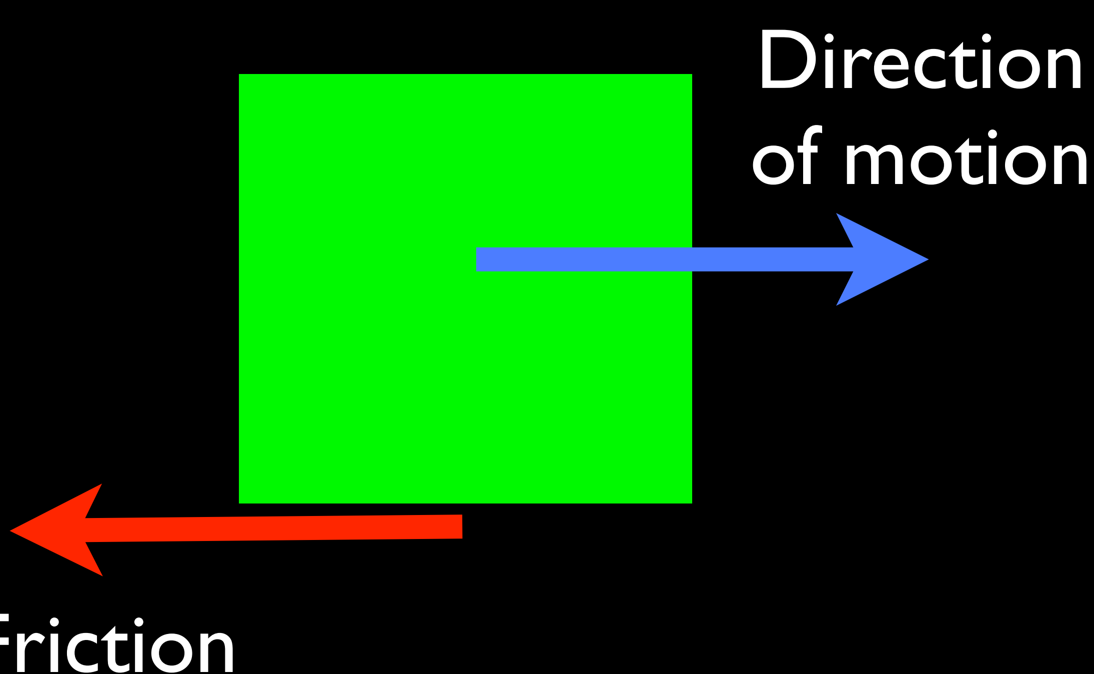
Friction is the force that exists between two objects in contact.



A surface might look smooth,

but at microscopic level it is far more irregular.

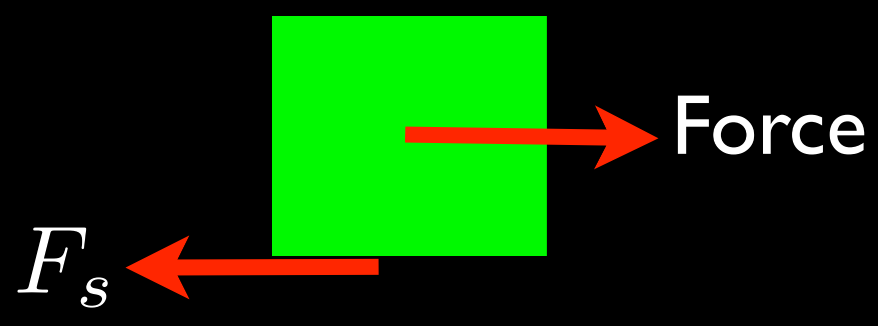
It is proportional to the normal force.



It always acts against the direction of motion

Friction

There are 2 kinds of friction:

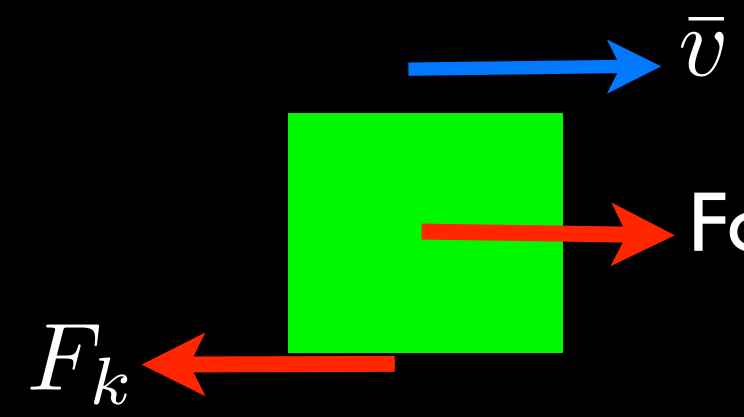


Static friction exists between 2 surfaces not moving relative to each other.

$$F_s \leq \mu_s N$$

μ_s is the coefficient of static friction

Range 0 to max value.
The max value depends on the type of surface.



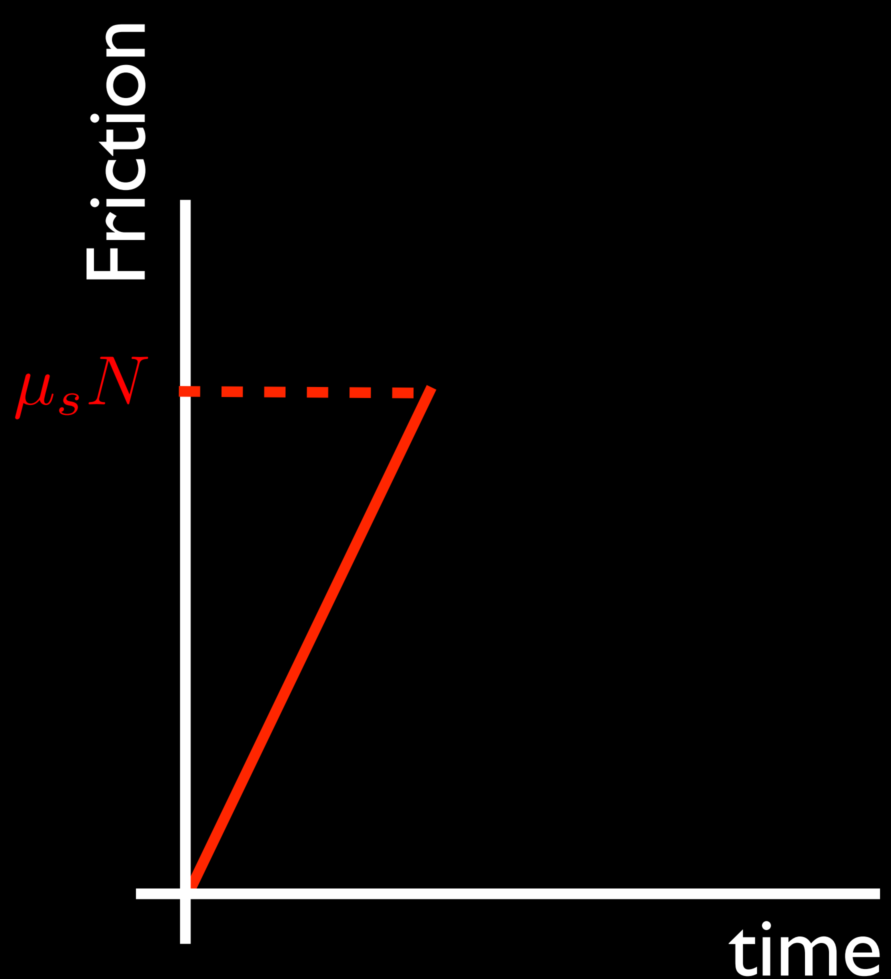
Kinetic friction exists between 2 surfaces that are moving relative to each other.

$$F_k = \mu_k N$$

μ_k is the coefficient of kinetic friction

Friction

static friction $\mu_s > \mu_k$ kinetic friction



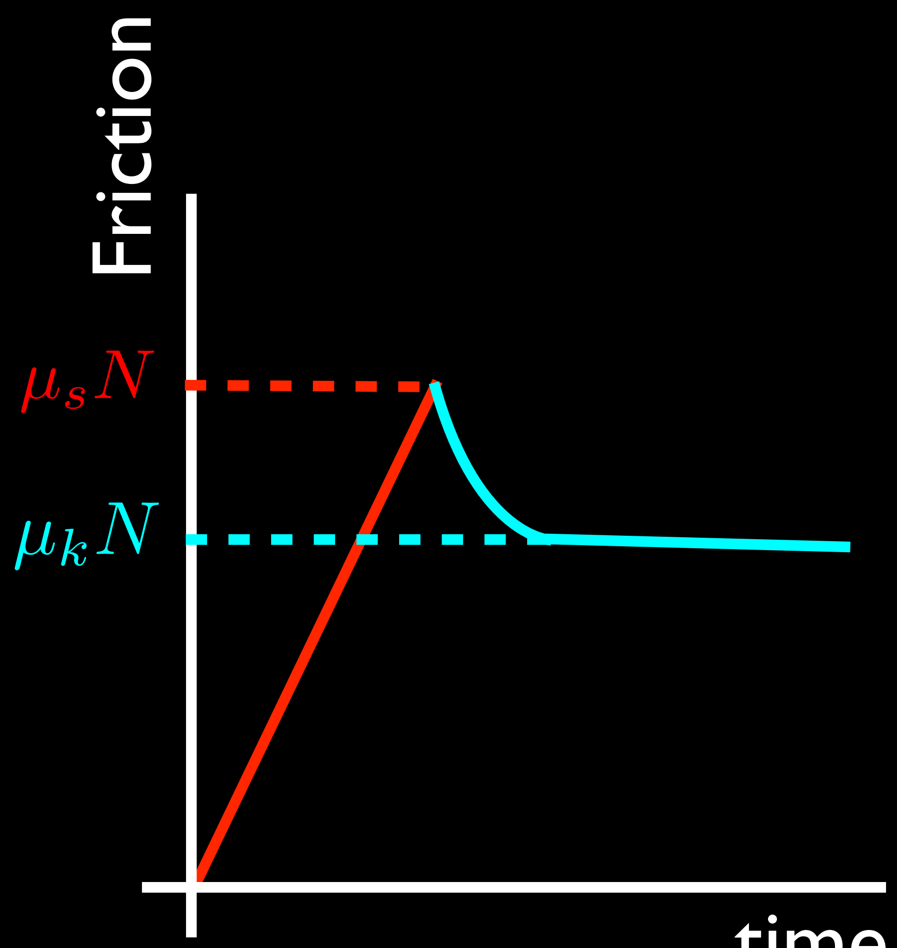
Pushing a heavy object:

It is very hard to start moving.

F_s increases as your force increases

Friction

static friction $\mu_s > \mu_k$ kinetic friction



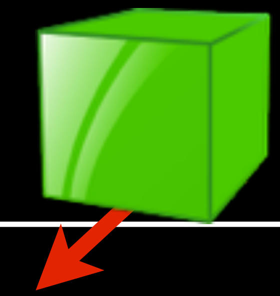
Pushing a heavy object:

It is very hard to start moving.
F_s increases as your force increases

Once it is moving, it is easier to push.

F_s is replaced by F_k

Friction



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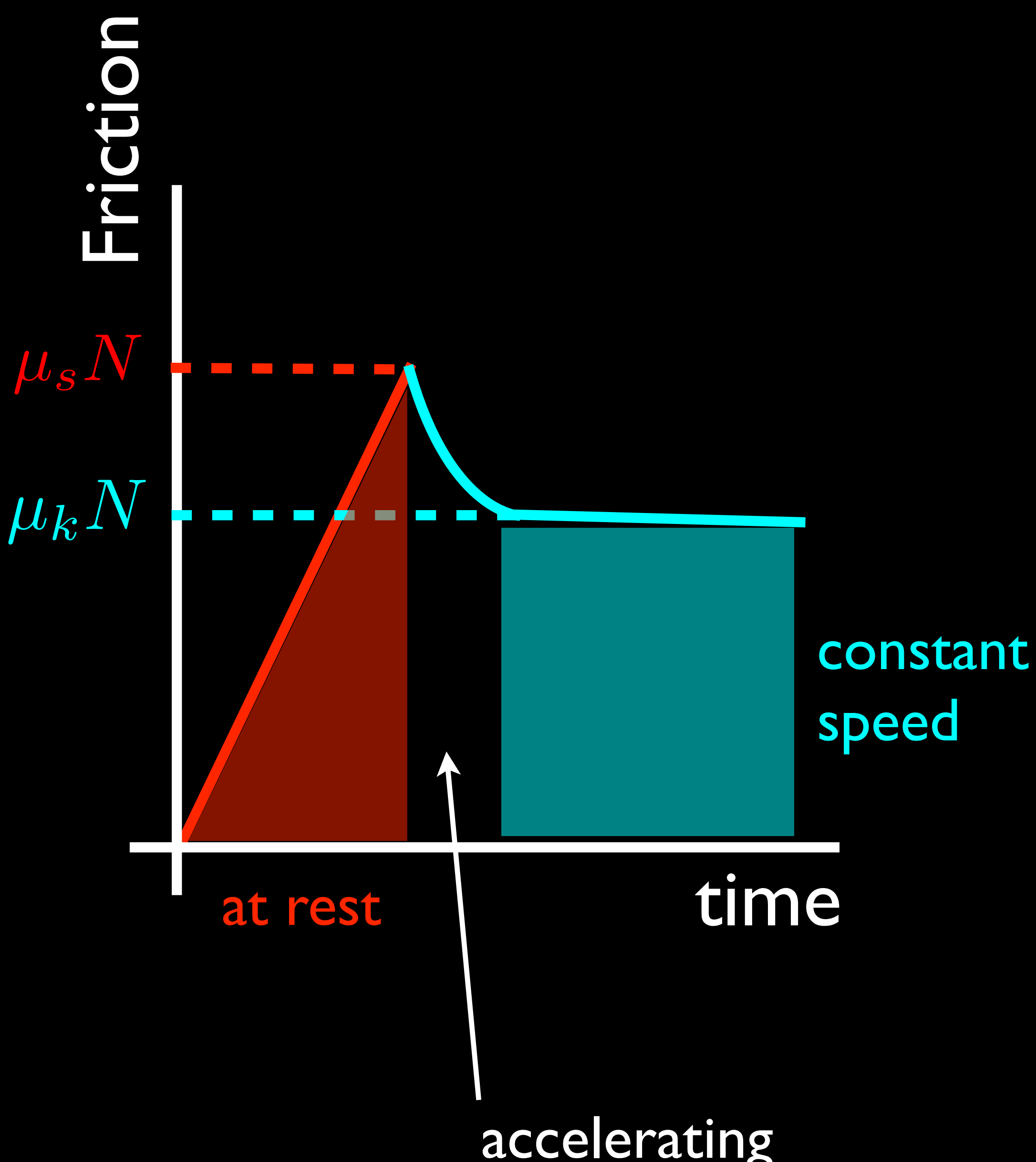

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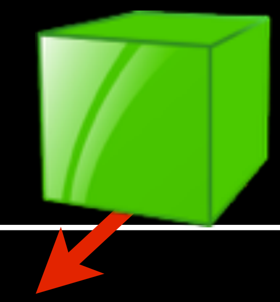
Friction



material 1	material 2	μ_s	μ_k
ice	ice	0.01	0.01
wood	wood	0.25	0.129
leather	wood	0.61	0.52
leather	metal	0.61	0.25
glass	glass	0.9 - 1.0	0.4
rubber	concrete (wet)	0.3	0.25
rubber	concrete (dry)	1	0.8
waxed ski	snow	0.1	0.05

Friction

Quiz

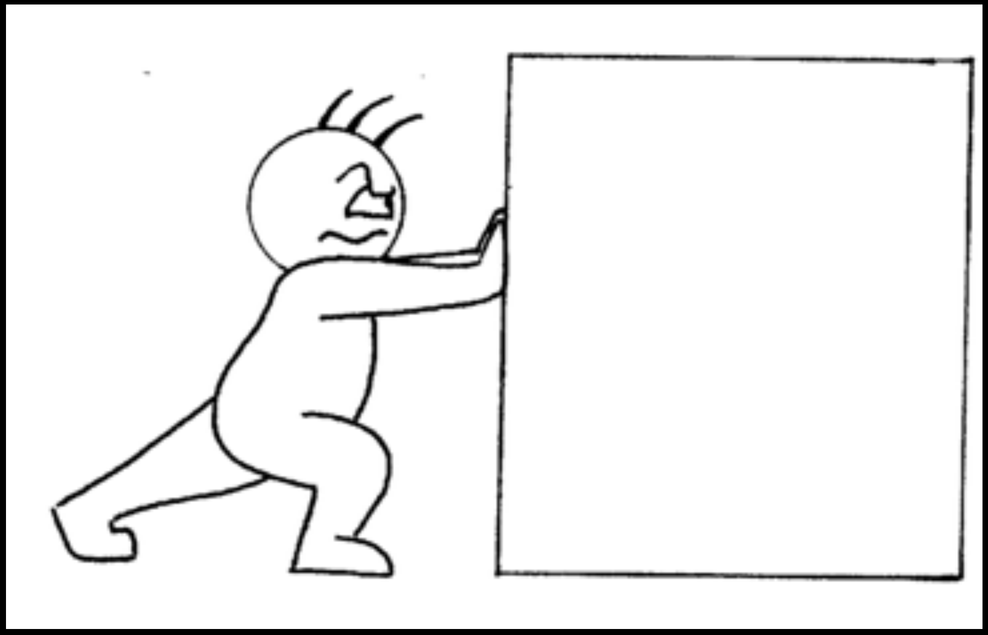
A man pushes a 73 kg box along a floor where the coefficient of kinetic friction is 0.81. What is the frictional force on the cabinet?

(a) 120 N

(b) 580 N

(c) 240 N

(d) 59.1 N



Friction

Quiz

A man pushes a 73 kg box along a floor where the coefficient of kinetic friction is 0.81. What is the frictional force on the cabinet?

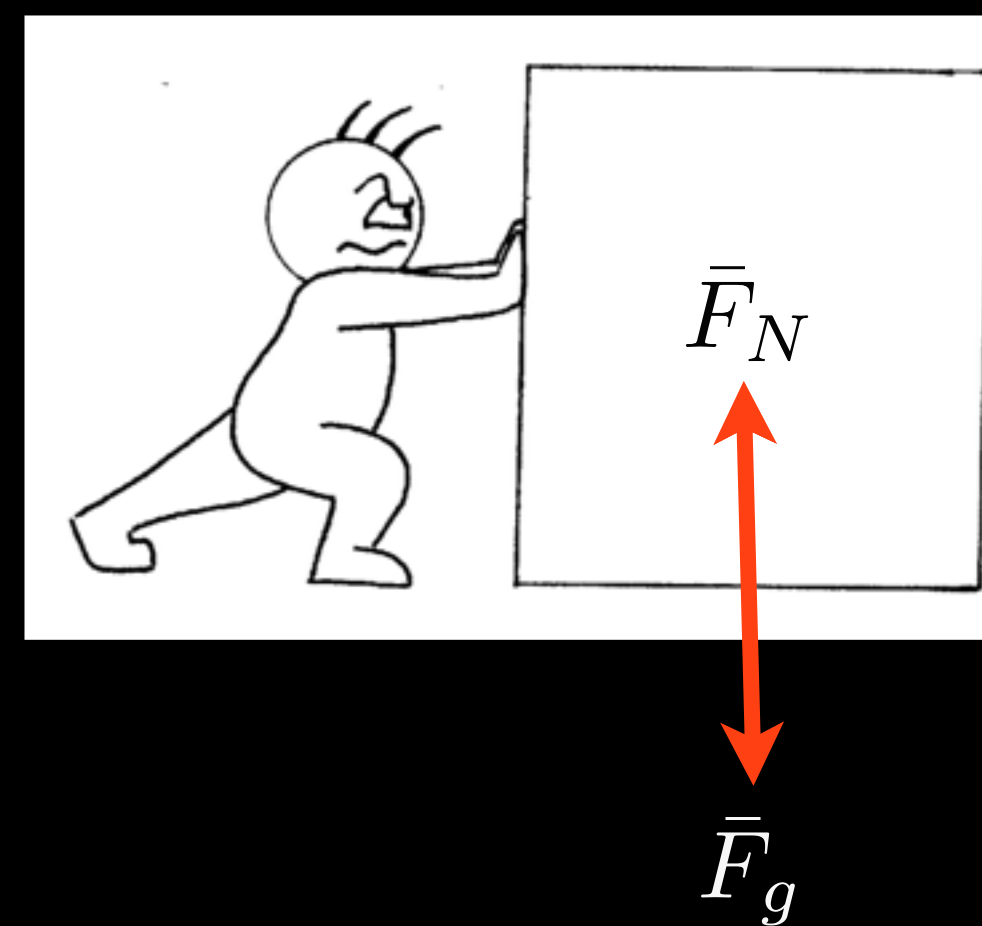
$$\bar{F}_{\text{friction}} = \mu_K \bar{F}_N$$

Newton 2nd: $\bar{F} = m\bar{a}$

vertical component: $\bar{F}_N - \bar{F}_g = m \times 0$

$$\bar{F}_N = \bar{F}_g$$

$$= mg$$



$$\bar{F}_{\text{fric}} = (0.81)(73\,\text{kg})(9.81\,\text{m/s}^2)$$

$$= 580\,\text{N}$$

Friction

Quiz

A hockey puck is given an initial velocity of 14 m/s. If it comes to a rest in 56 m, what is the coefficient of kinetic friction?

(a) 0.0

(b) 0.36

(c) 0.18

(d) 0.21

Friction

Quiz

A hockey puck is given an initial velocity of 14 m/s. If it comes to a rest in 56 m, what is the coefficient of kinetic friction?

horizontal component:

$$v^2 = v_0^2 + 2a(x - x_0)$$

0

$$a = -\frac{v_0^2}{2(x - x_0)}$$

Newton 2nd: $\bar{F} = m\bar{a}$

vertical: $\bar{F}_N - \bar{F}_g = m \times 0$

$$\bar{F}_N = \bar{F}_g$$

$$= mg$$

Friction

Quiz

A hockey puck is given an initial velocity of 14 m/s. If it comes to a rest in 56 m, what is the coefficient of kinetic friction?

Newton 2nd: $\bar{F} = m\bar{a}$

horizontal: $F_{\text{fric}} = -\mu_K F_N = ma$

$$-\mu_K mg = ma$$

$$-\mu_K = -\frac{a}{g} = -\frac{v_0^2}{2g(x - x_0)}$$

$$= -\frac{(14\,\mathrm{m/s})^2}{2(9.81\,\mathrm{m/s^2})(56\,\mathrm{m})}$$

$$= 0.18$$

Friction

Example

2 children are pulled on a sled on snow.

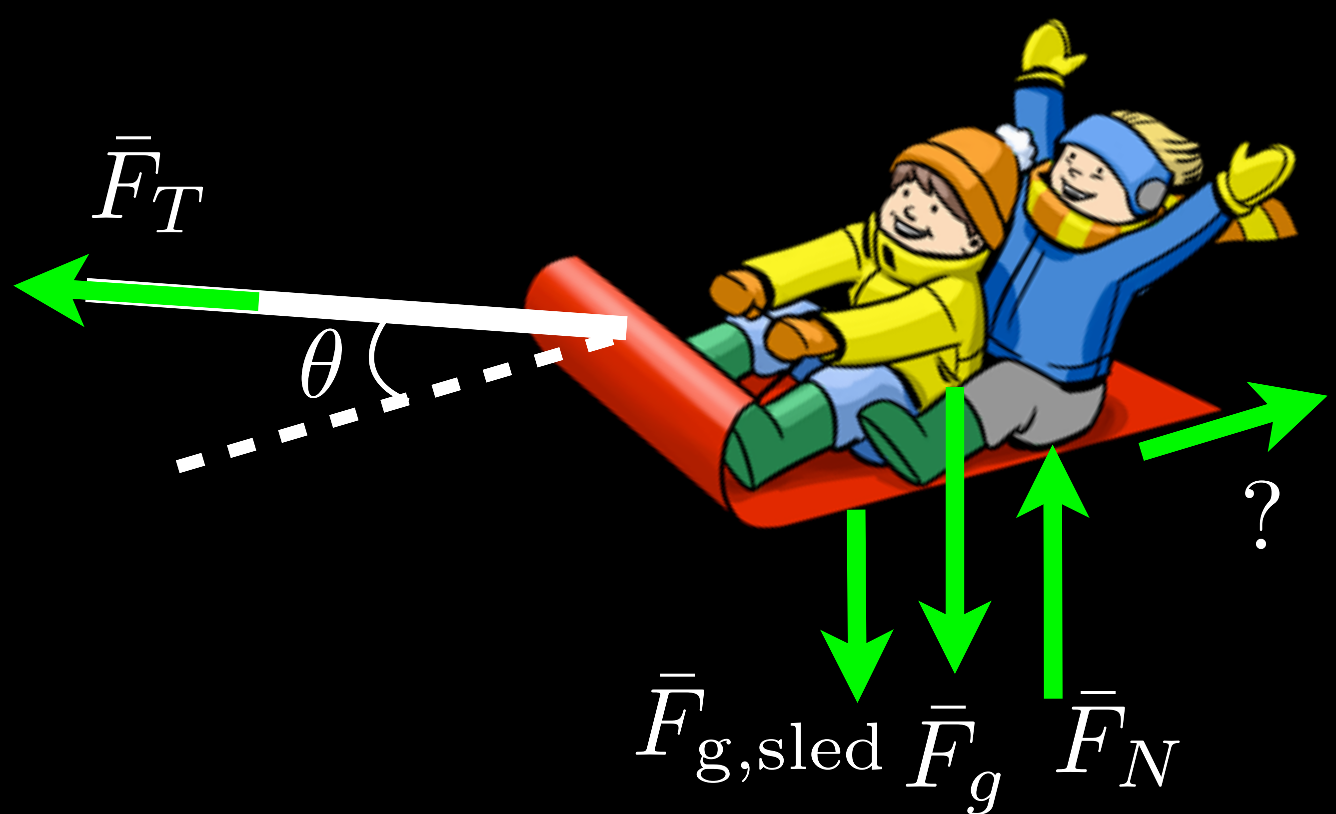
The sled is pulled by a rope that makes an angle of 40° with the horizontal.

The children have a total mass of 45 kg and the sled mass is 5 kg.

The coefficients of friction are $\mu_s = 0.2$ and $\mu_k = 0.15$.

Find the frictional force exerted by the ground on the sled and the acceleration of the sled if the tension in the rope is:

(a) 100 N
(b) 140 N.



Friction

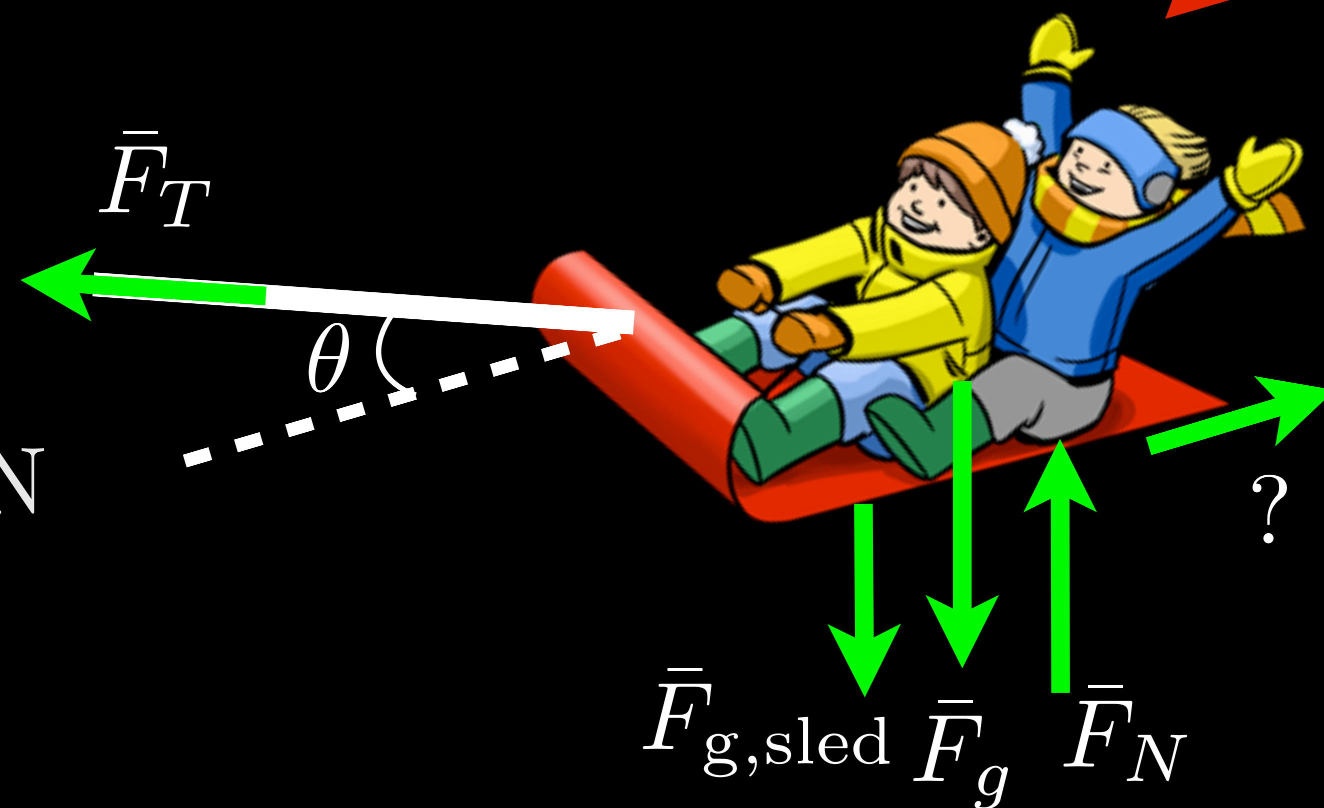
Example

(a) $\bar{F}_{\mathrm{T}} = 100\,\mathrm{N}$

Rope tension components:

$$F_{T,x} = F_T \cos 40^\circ$$
$$= (100\,\mathrm{N})(0.766) = 76.6\,\mathrm{N}$$

$$F_{T,y} = F_T \sin 40^\circ$$
$$= (100\,\mathrm{N})(0.643) = 64.3\,\mathrm{N}$$



vertical Newton 2nd: $\bar{F} = m\bar{a}$

$$F_{\mathrm{N}} + F_{\mathrm{T,y}} + F_g = m \times 0 \qquad (a_y = 0)$$

$$F_{\mathrm{N}} = mg - F_{\mathrm{T,y}} \ = (50\,\mathrm{kg})(9.81\,\mathrm{m/s^2}) - 64.3\,\mathrm{N}$$

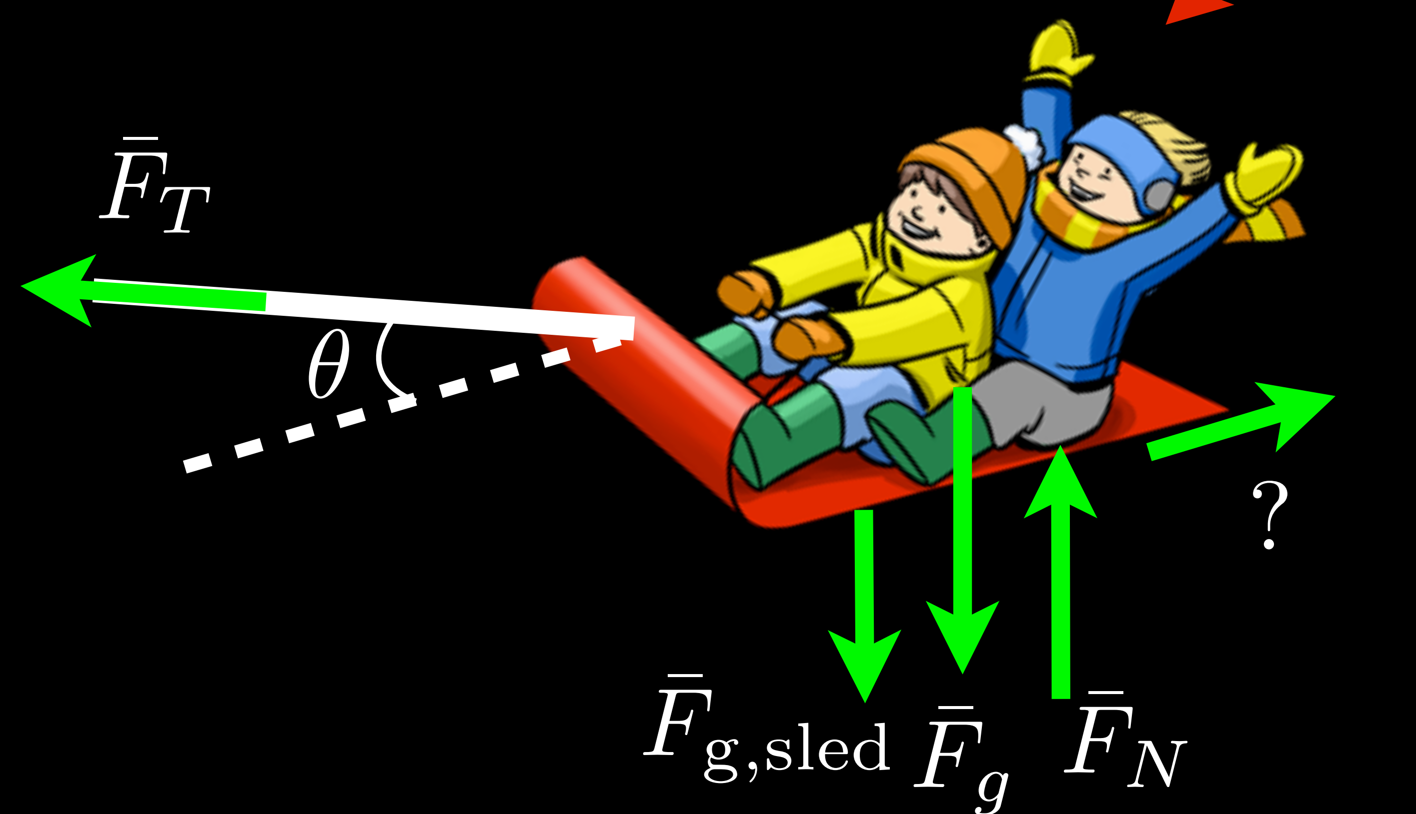
$$= 426\,N$$

Friction

Example

Maximum static friction:

$$F_{\mathrm{s,max}} = \mu_s F_{\mathrm{N}}$$
$$= 0.2(426\,\mathrm{N}) = 85.2\,\mathrm{N}$$



since:

$F_{\mathrm{T,x}} = 76.6\,\mathrm{N} < F_{\mathrm{s,max}}$ sled doesn't move.

Therefore friction force is:

$$F_{\mathrm{friction}} = F_{\mathrm{s}} = F_{\mathrm{T,x}} = 76.6\,\mathrm{N}$$

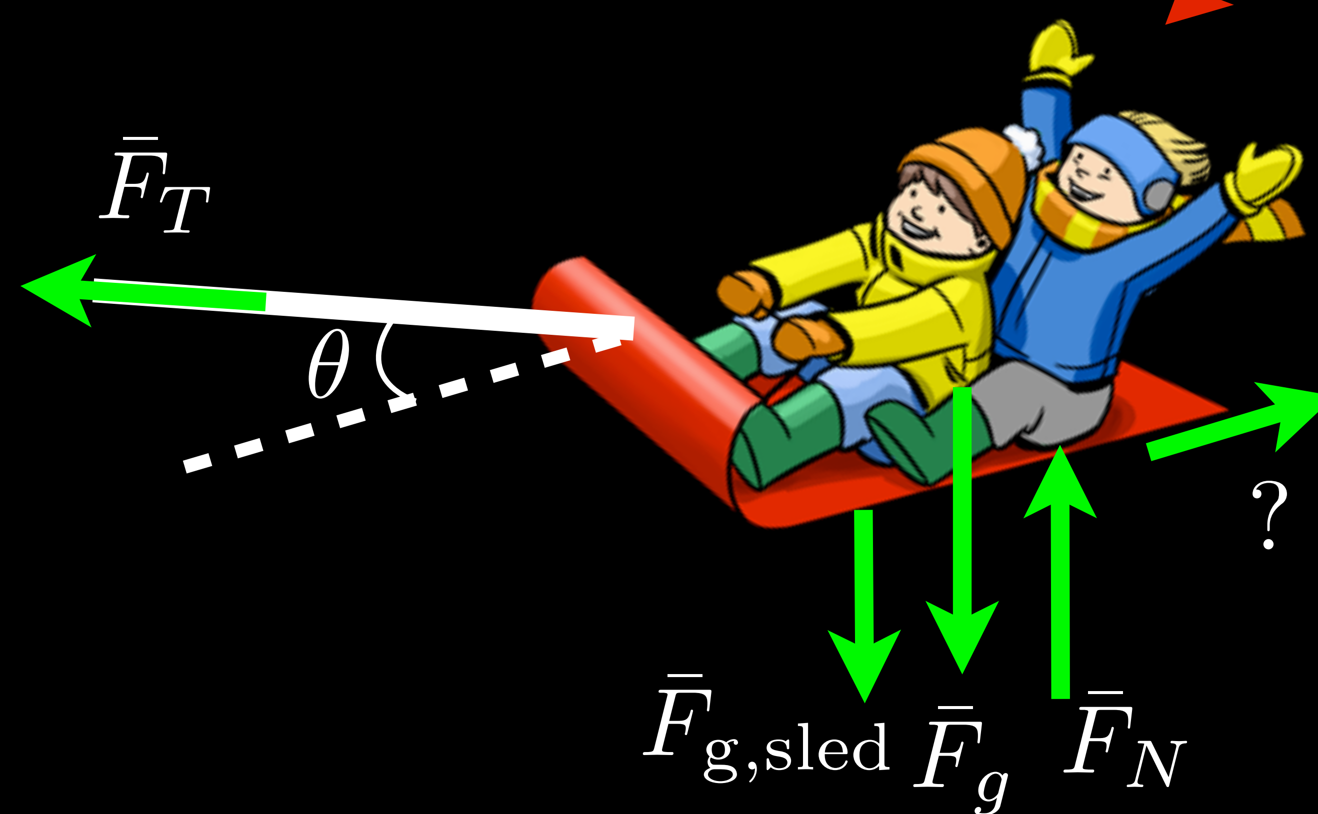
(less than maximum value)

Friction

Example

(b) $\bar{F}_\mathrm{T} = 140\,\mathrm{N}$

Rope tension components:



$$F_\mathrm{T,x} = 140\,\mathrm{N}\cos 40^\circ = 107\,\mathrm{N}$$

$$F_\mathrm{T,y} = 140\,\mathrm{N}\sin 40^\circ = 90\,\mathrm{N}$$

vertical Newton 2nd: $\bar{F} = m\bar{a}$

$$F_\mathrm{N} = mg - F_\mathrm{T,y} = 490\,\mathrm{N} - 90\,\mathrm{N} = 400\,\mathrm{N}$$

Maximum static friction:

$$F_\mathrm{s,max} = \mu_s F_\mathrm{N} = 0.2(400\,\mathrm{N}) = 80.0\,\mathrm{N}$$

$F_\mathrm{s,max} < F_\mathrm{T,x}$ $\longrightarrow$ sled will move.

frictional force will be kinetic friction

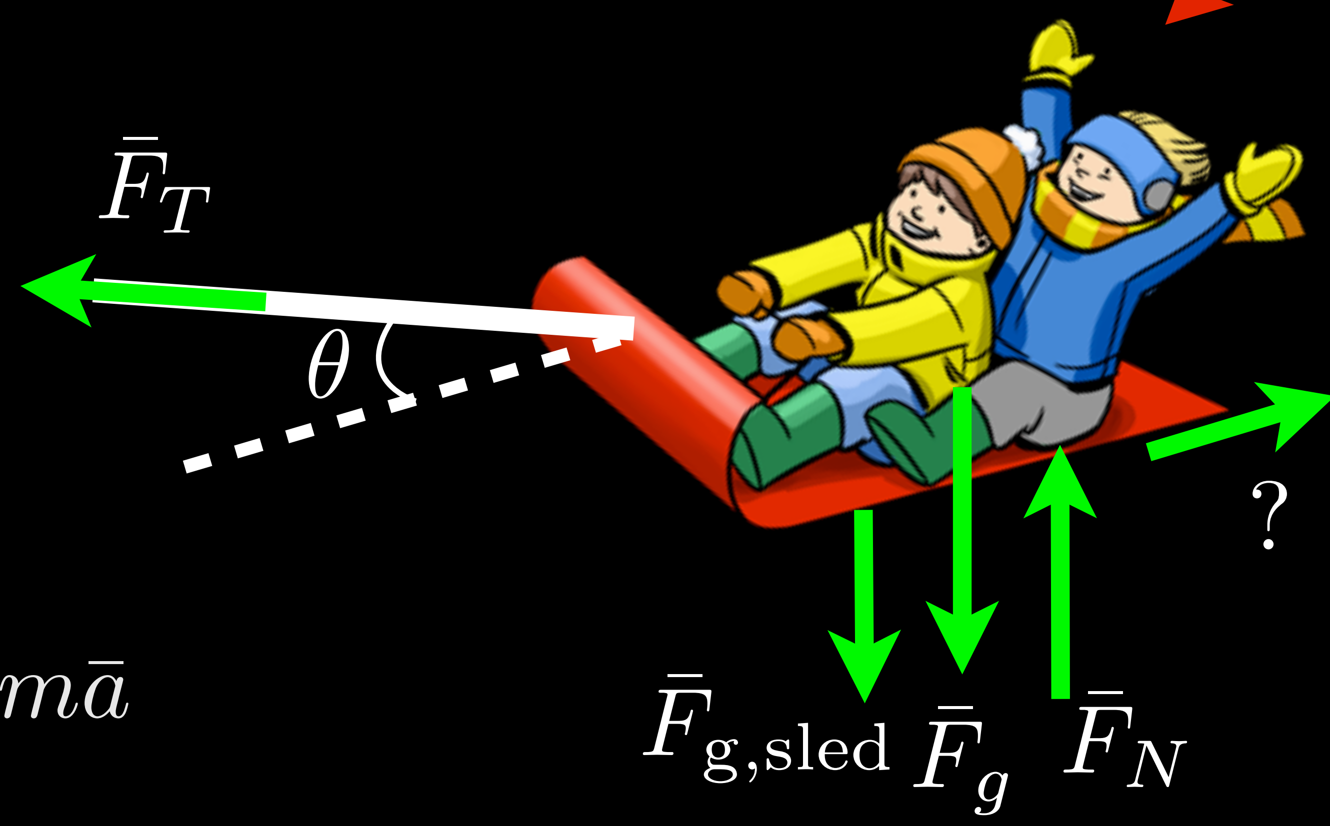
Friction

Example

Kinetic friction:

$$F_{\mathrm{K}} = \mu_K F_{\mathrm{N}}$$

$$= 0.15(400\,\mathrm{N}) = 60.0\,\mathrm{N}$$



horizontal Newton 2nd: $\bar{F} = m\bar{a}$

$$F_{\mathrm{T,x}} - F_{\mathrm{K}} = ma$$

$$107\,\mathrm{N} - 60\,\mathrm{N} = (50\,\mathrm{kg})a$$

$$a = \frac{107 - 60}{50} = 0.94\,\mathrm{m/s^2}$$

Friction

Quiz

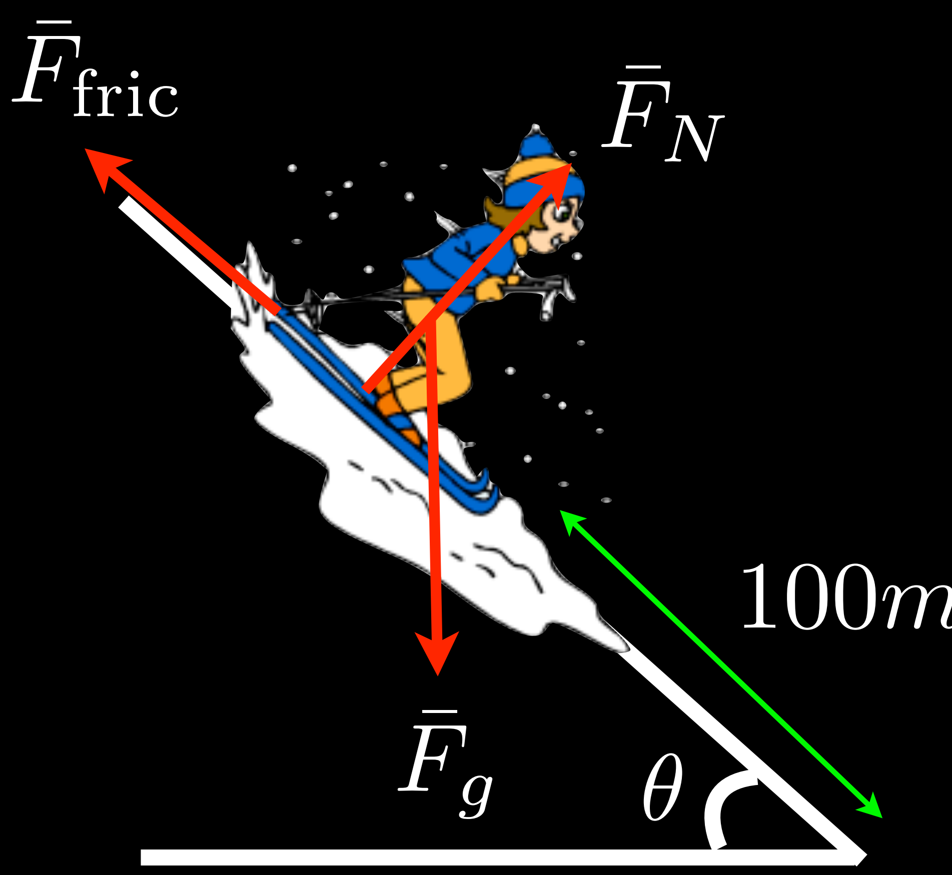
Starting from rest, a skier slides 100m down a 28° slope. How much longer does the run take if the coefficient of kinetic friction is 0.17 instead of 0?

(a) 1.4s

(b) 8s

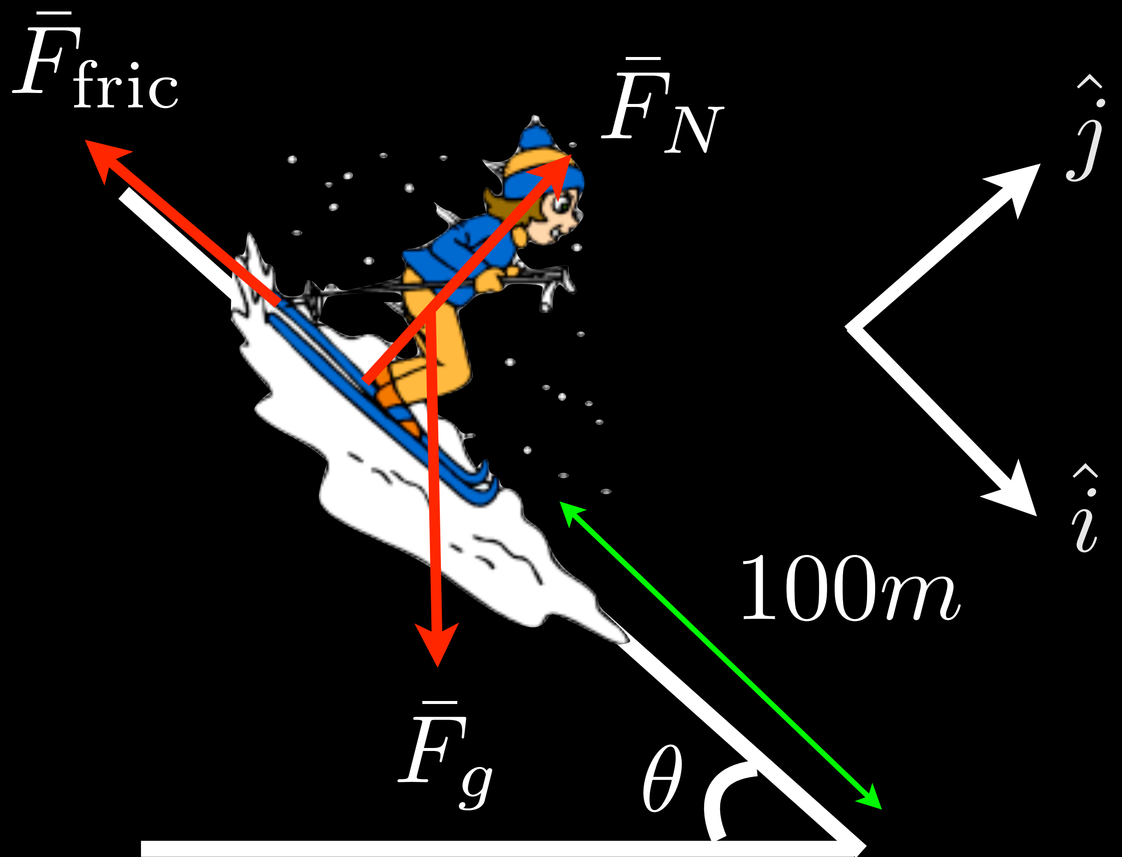
(c) 6.5s

(d) 13s



Friction

Quiz



Define co-ordinates:

$\hat{i}$ parallel to slope

$\hat{j}$ perpendicular to slope

Newton 2nd: $\bar{F} = m\bar{a}$ components:

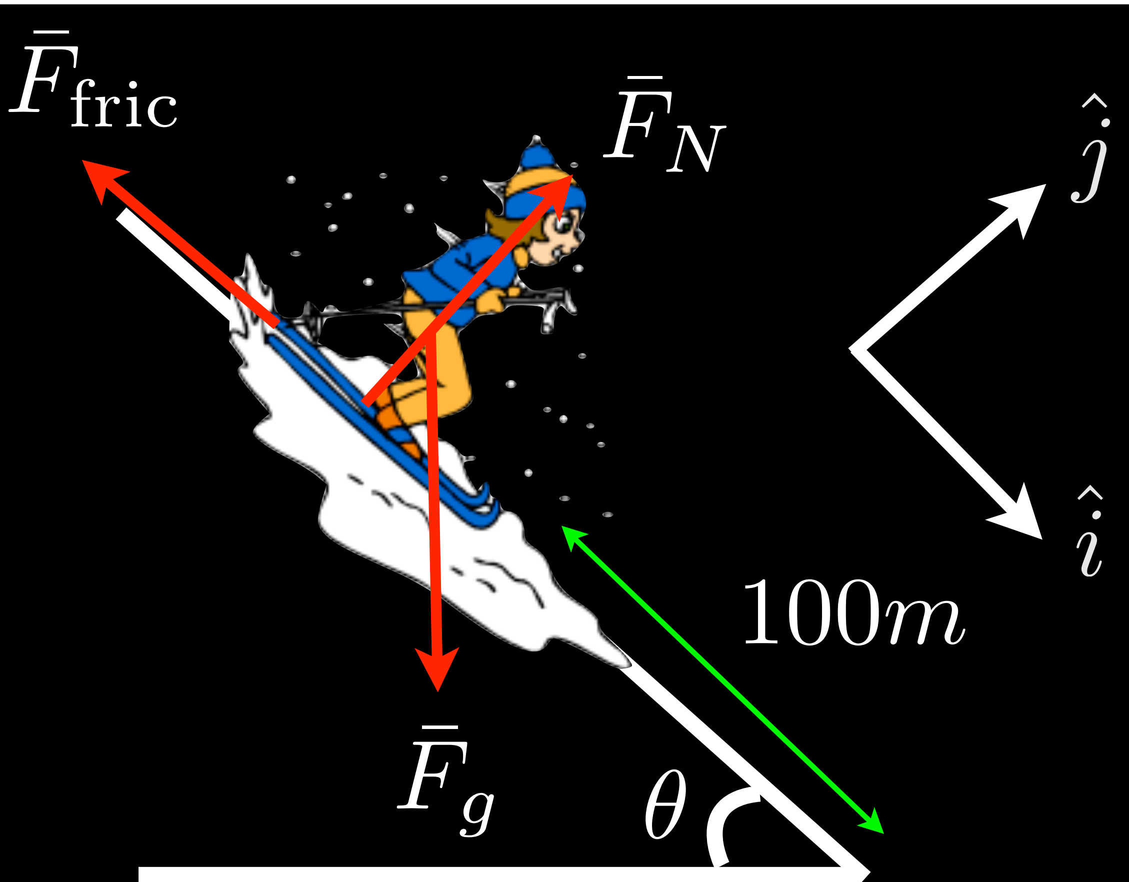
$\hat{i}$ $$-F_{\text{fric}} + F_g \sin\theta = ma_i$$

$\hat{j}$ $$F_{\text{N}} - F_g \cos\theta = ma_j = 0 \qquad (a_j = 0)$$

$$\longrightarrow \quad F_{\text{N}} = mg\cos\theta \qquad (F_g = mg)$$

Friction

Quiz



Therefore, kinetic friction:

$$\bar{F}_{\text{fric}} = \mu_K \bar{F}_N \quad = \mu_K mg\cos\theta$$

(a) $\mu_K = 0 \longrightarrow \bar{F}_{\text{fric}} = 0$

$\hat{i}$ $\quad -F_{\text{fric}} + F_g \sin\theta = ma_i$

0

$$a_i = g\sin\theta$$

Constant acceleration question in $\hat{i}$ direction:

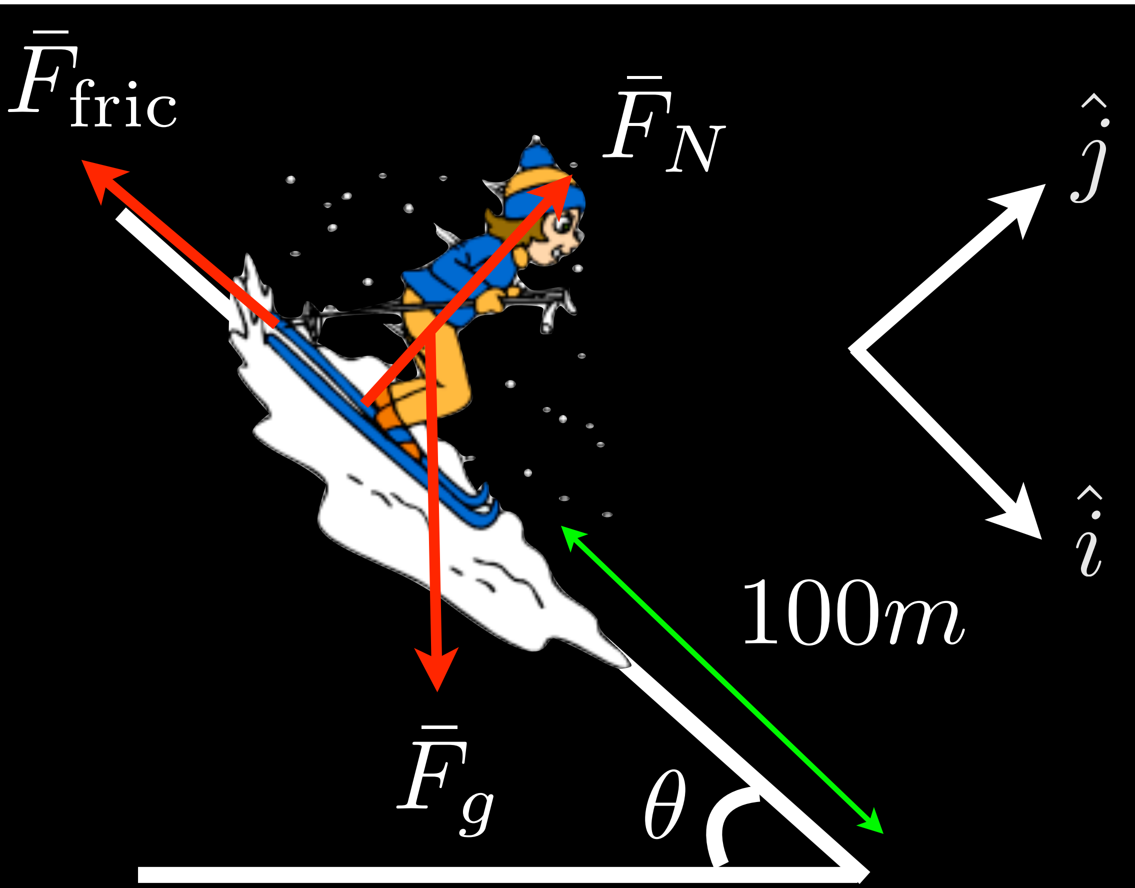
$$x_i = x_{0,i} + v_{0,i}t + \frac{1}{2}a_i t^2$$

0

$$t_a = \sqrt{\frac{2(x_i - x_{0,i})}{a_i}} = \sqrt{\frac{2(100)}{9.81\sin 28^\circ}} = 6.59\,\text{s}$$

Friction

Quiz



(b) $\mu_K = 0.17$

$$\longrightarrow \quad \bar{F}_{\text{fric}} = 0.17mg\cos\theta$$

$$\hat{i} \quad -F_{\text{fric}} + F_g \sin\theta = ma_i$$

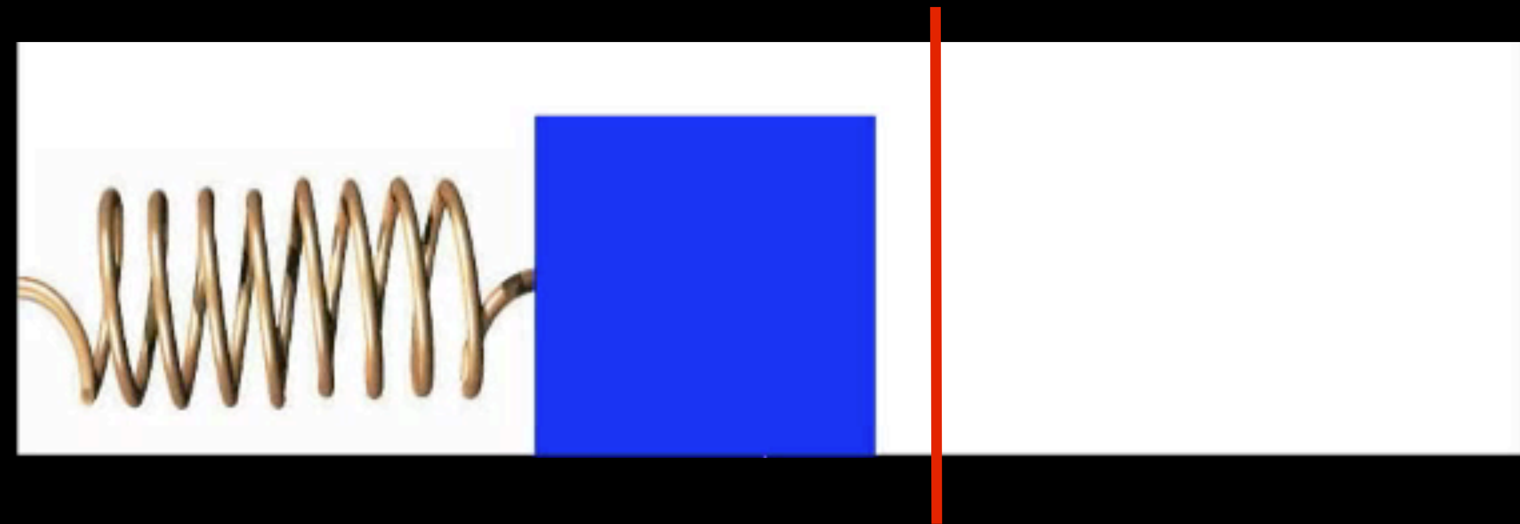
$$a_i = -0.17g\cos\theta + g\sin\theta$$

$$t_b = \sqrt{\frac{2(x - x_0)}{a_i}} = \sqrt{\frac{2(100)}{(9.81)(\sin 28° - 0.17\cos 28°)}} = 7.99\,\text{s}$$

$$t_b - t_a = 7.99 - 6.59 = 1.4\,\text{s}$$

Springs

Ideal spring:



Displacement from equilibrium is proportional to the force it produces:

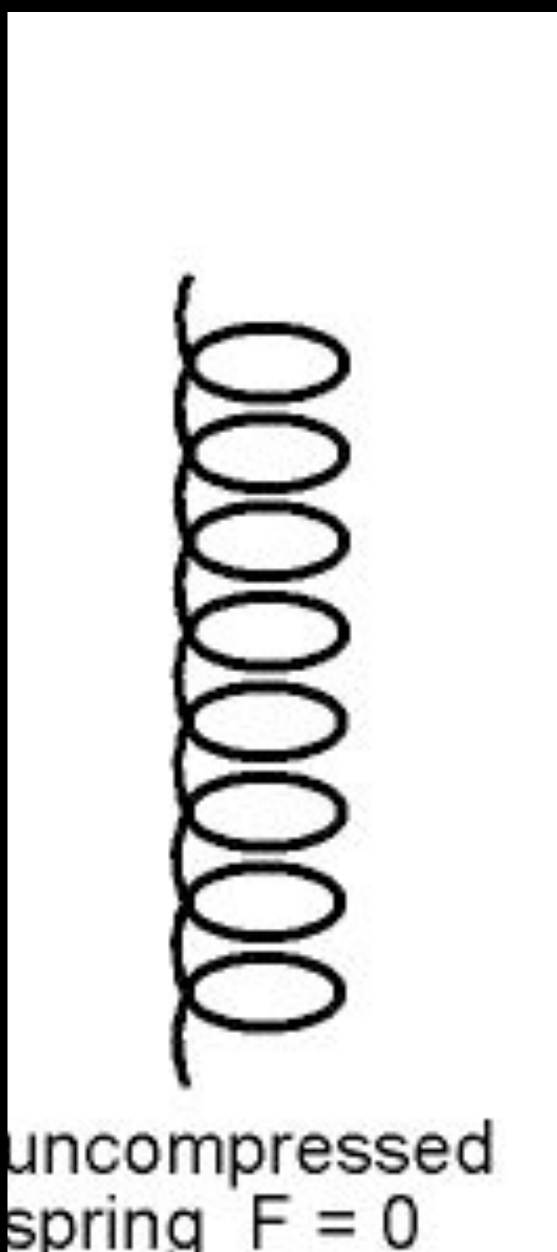
$$\bar{F}_{\text{sp}} = -k\Delta x$$

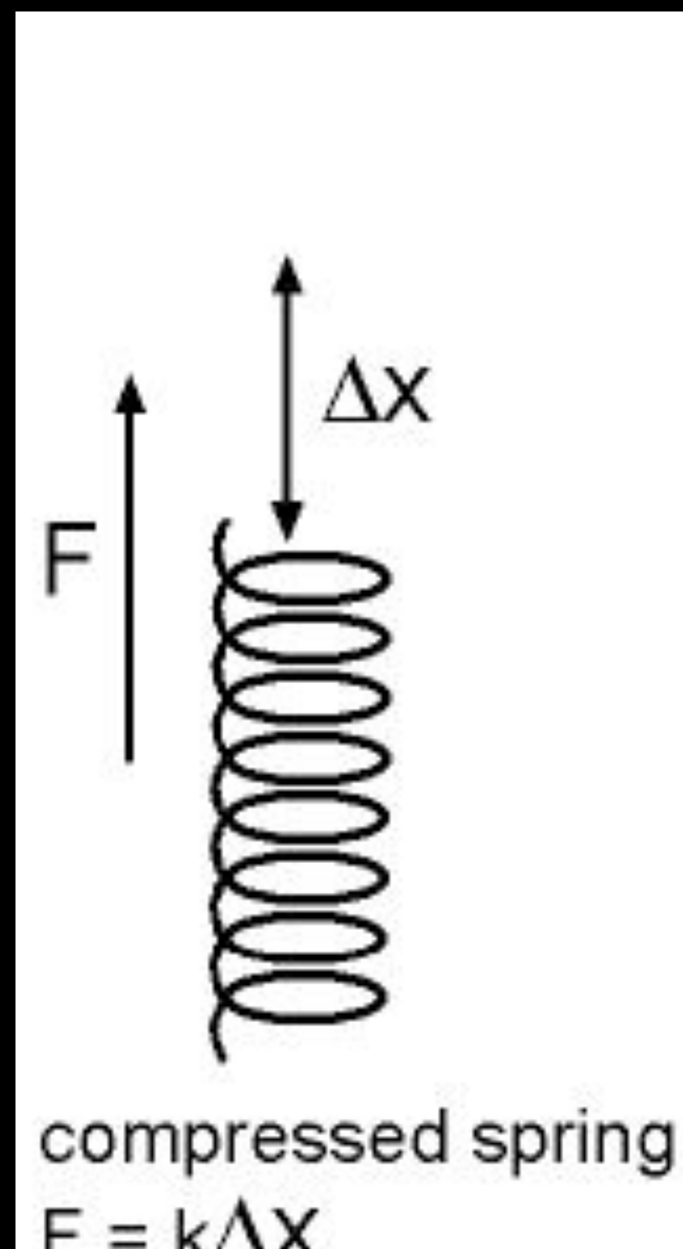
Hooke's law

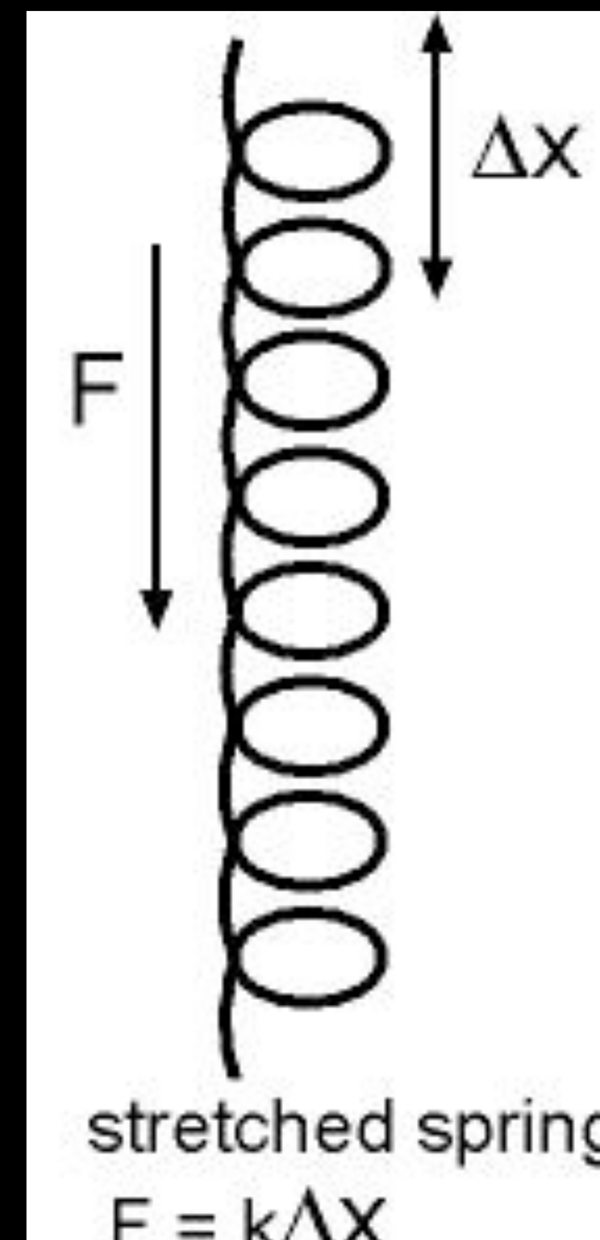
k : spring constant, measure of spring stiffness

Springs

$$\bar{F}_{\text{sp}} = -k\Delta x$$ Hooke's law



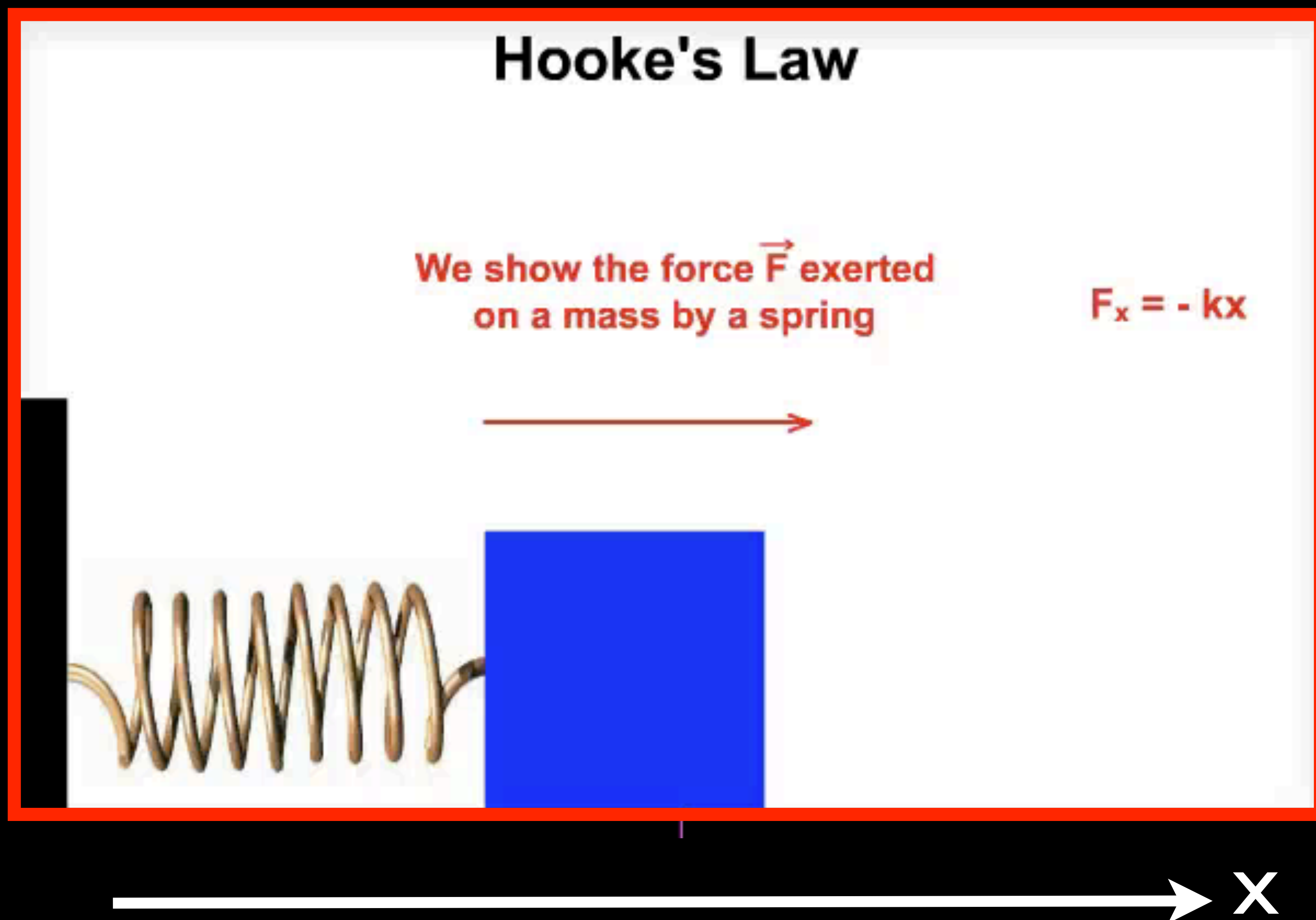




equilibrium

Springs

$$\bar{F}_{\mathrm{sp}} = -k\Delta x$$ Hooke's law



Springs

Quiz 

What force is needed to stretch a spring by 48 cm, if the spring constant is 270 N/m?

(a) -12,960 N

(b) 12,960 N

(c) 130 N

(d) -130 N

Springs

Quiz

What force is needed to stretch a spring by 48 cm, if the spring constant is 270 N/m?

Hooke's law: $\bar{F}_{\rm sp} = -k\Delta x$

$$= -(270\,{\rm N.m})(0.48\,{\rm m}) = -130\,{\rm N}$$

(applied force, $\bar{F}_{\rm app}$) = - (spring resistance, $\bar{F}_{\rm sp}$)

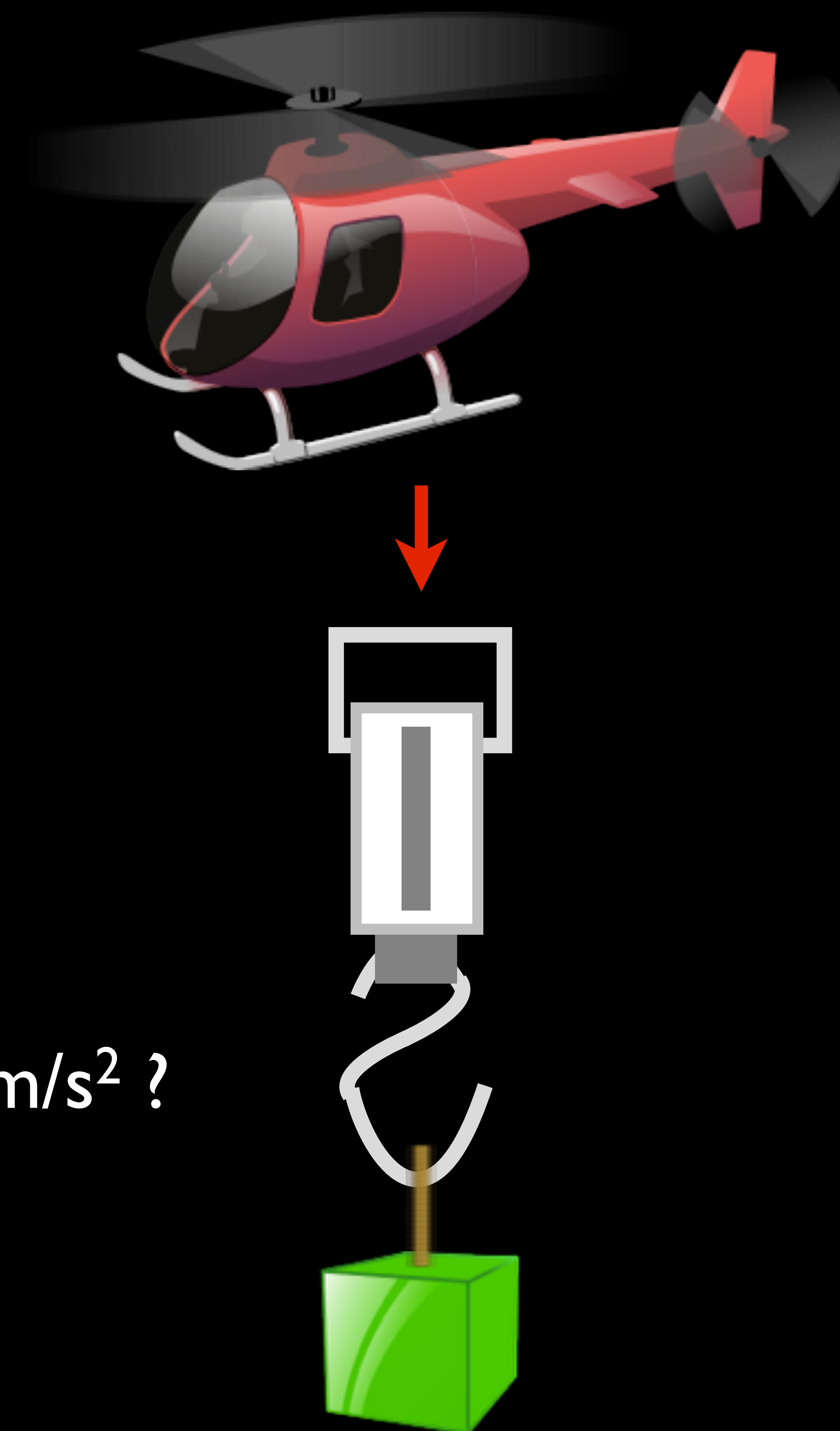
$$\bar{F}_{\rm app} = -\bar{F}_{\rm sp}$$

$$= 130\,{\rm N}$$

Springs

Example

A helicopter rises vertically, carrying a 35 kg block on a spring scale. The spring constant is $k = 3.4$ kN/m.



How much does the spring extend

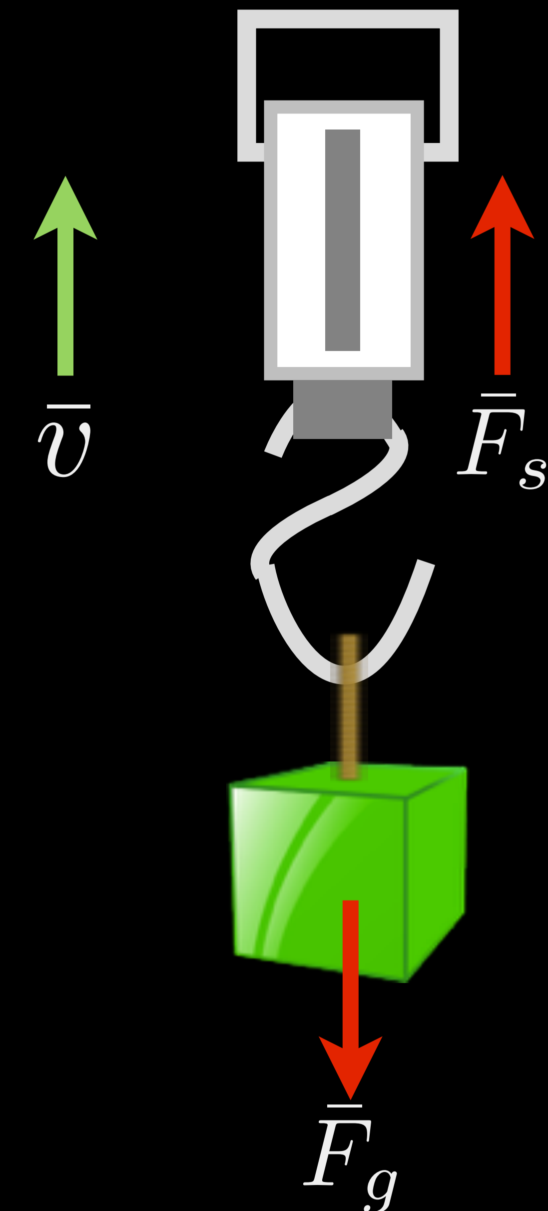
(a) when the helicopter is at rest?

(b) when its accelerating upwards at 1.9 m/s^2 ?

Springs

Example

A helicopter rises vertically, carrying a 35 kg block on a spring scale. The spring constant is k = 3.4 kN/m.



vertical Newton 2nd: $\bar{F} = m\bar{a}$

$$F_s + F_g = ma \longrightarrow kx - mg = ma$$

$$x = \frac{m(a+g)}{k}$$

(a) $\bar{v} = 0$ (helicopter at rest) $x = \frac{(35\,\mathrm{kg})(0 + 9.81\,\mathrm{m/s^2})}{3400\,\mathrm{N/m}} = 10\,\mathrm{cm}$

(b) $\bar{a} = 1.9\,\mathrm{m/s^2}$ $x = \frac{(35\,\mathrm{kg})(1.9 + 9.81\,\mathrm{m/s^2})}{3400\,\mathrm{N/m}} = 12\,\mathrm{cm}$

Springs

Quiz

2 large crates, with masses 640 kg and 490 kg, are connected by a stiff massless spring with k = 8.1 kN/m.

They are moved along a frictionless floor by a horizontal force applied to the more massive crate.

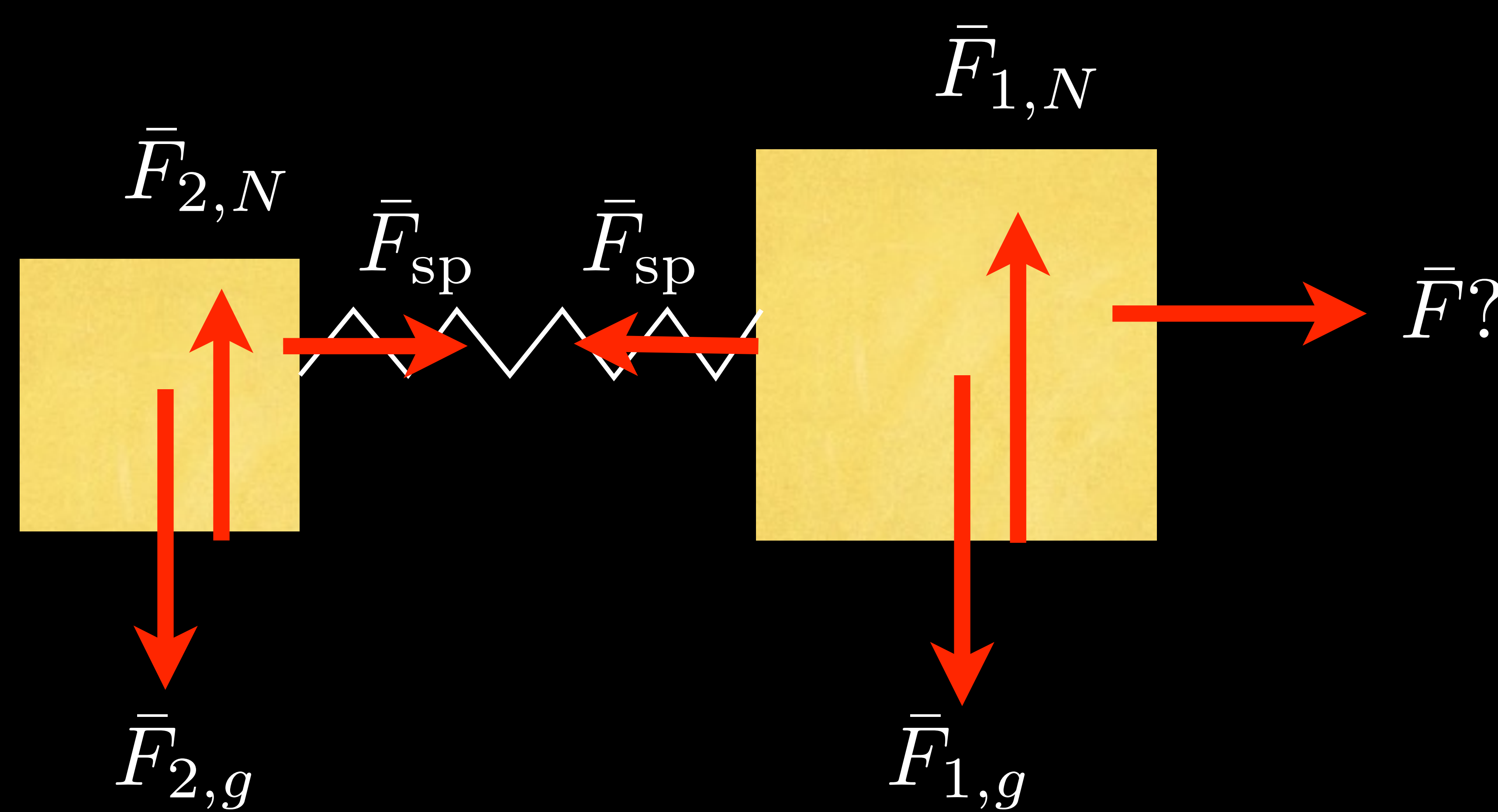
If spring extends 5.1 cm, what is the applied force?

(a) 0.1 N

(b) 540 N

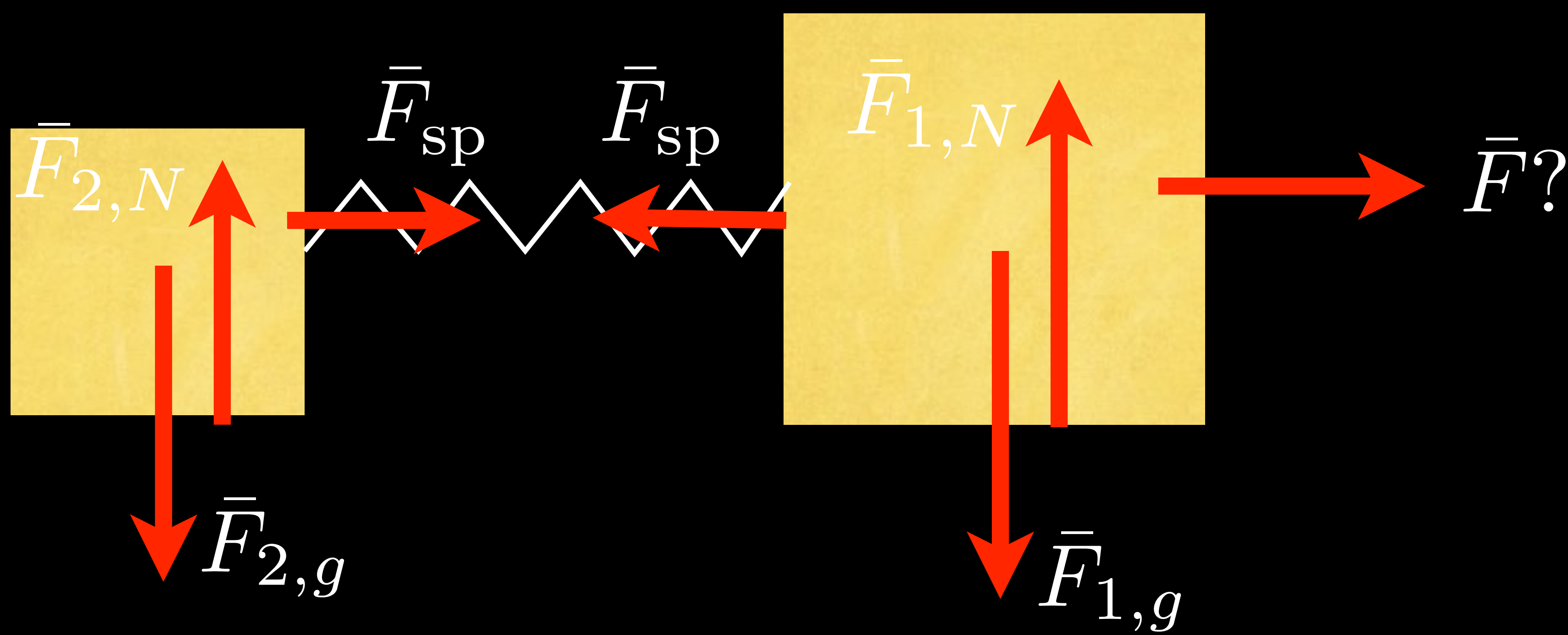
(c) 953 N

(d) 950 N



Springs

Quiz



Block 1: $\bar{F}_{\text{net},1} = \bar{F} - \bar{F}_{\text{sp}} = m_1 a$

Block 2: $\bar{F}_{\text{net},2} = \bar{F}_{\text{sp}} = m_2 a$ → $a = \dfrac{\bar{F}_{\text{sp}}}{m_2}$

$$\bar{F} = \bar{F}_{\text{sp}} + m_1 \left(\frac{\bar{F}_{\text{sp}}}{m_2} \right) = k\Delta x \left(\frac{m_1 + m_2}{m_2} \right)$$

$$= (8100\,\text{N/m})(0.051\,\text{m}) \left(\frac{640 + 490\,\text{kg}}{490\,\text{kg}} \right) = 953\,\text{N}$$

Drag

Last lecture, we estimated the acceleration of a sky diver and found it much less than g

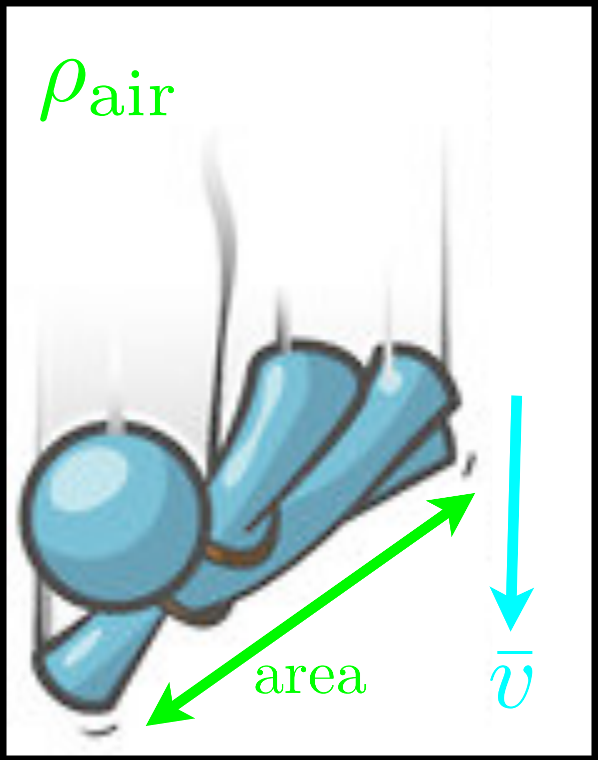
We concluded that we had neglected the drag force from air resistance

Drag forces depend on several factors including:

Fluid density

The object's cross-sectional area

The object's speed.



Drag

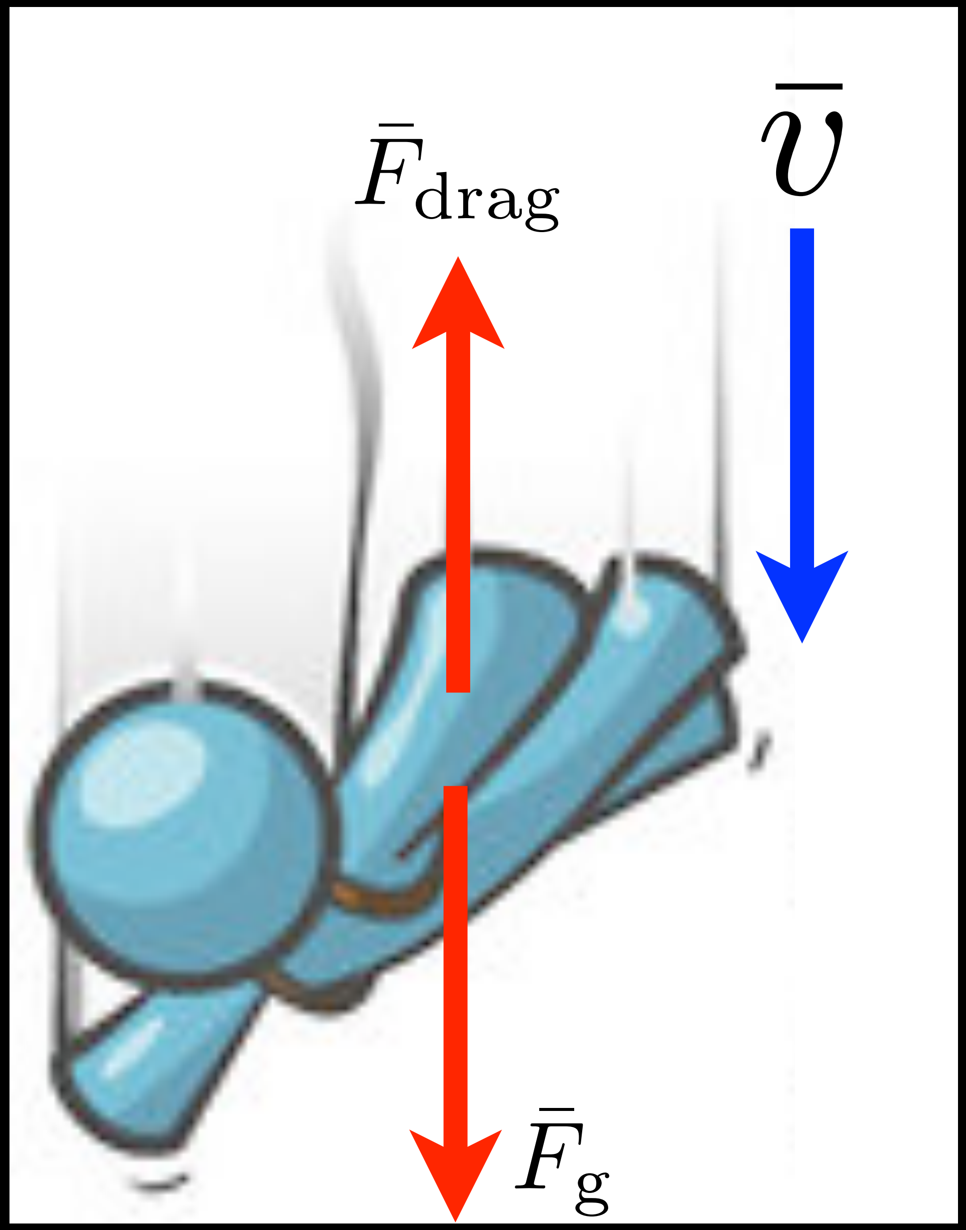
An object falling:

Speed is initially low, so drag is low.

As object gains speed, drag increases.

Eventually the drag force and gravity will be equal.

At this point $\bar{F}_{\mathrm{net}} = 0$, and the speed is constant, called the terminal speed.



Because drag depends on area and not on mass, a sheet of paper falls much slower than a golf ball.

Drag

Without drag they would fall at the same rate $\bar{F}_{\text{net}} = \cancel{m}g = \cancel{m}a$

Drag

Drag

Quiz

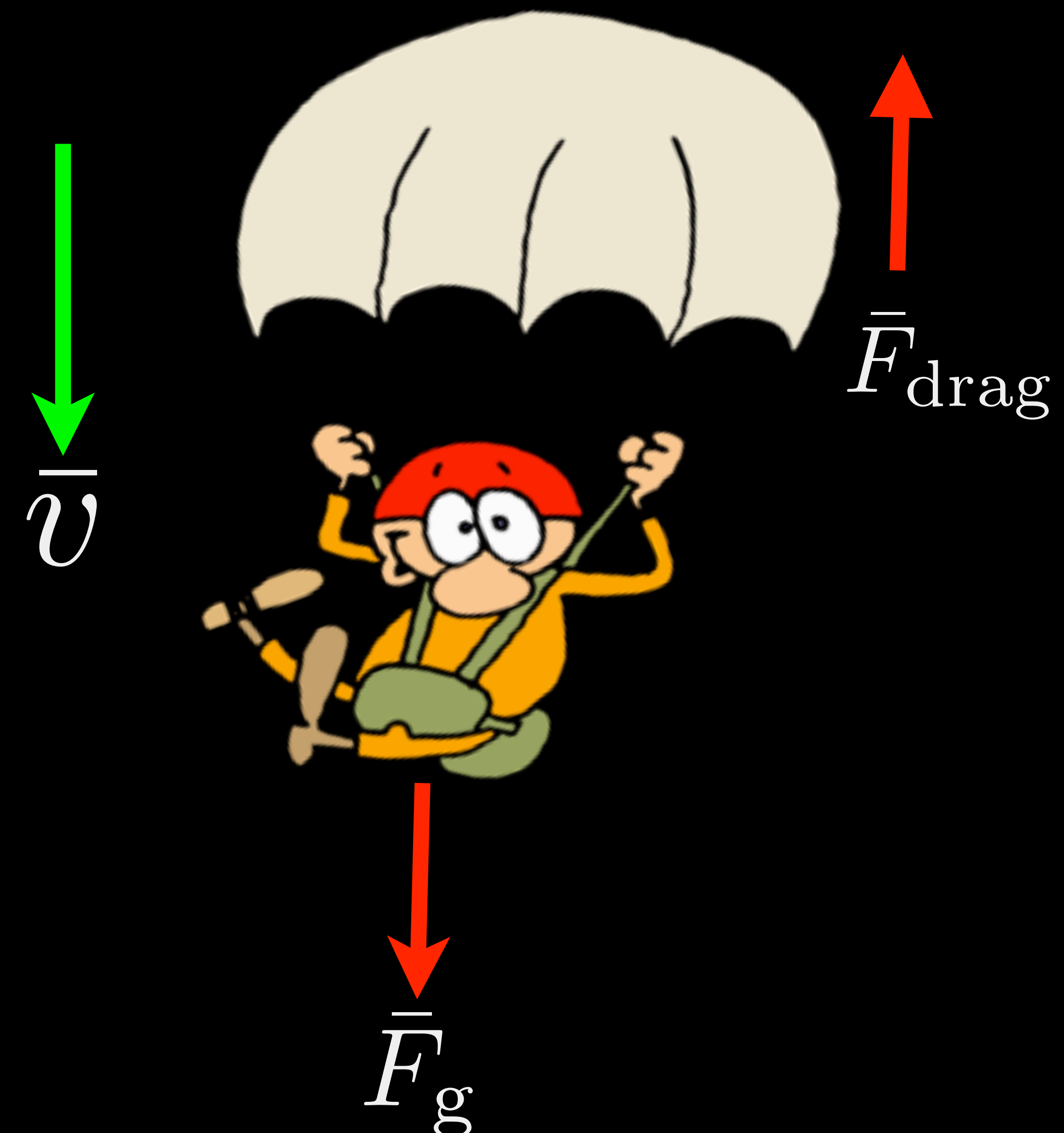
A 50kg parachute descends at a steady 40 km/h. What force does the air exert on the parachute?

(a) 490.5N

(b) 2000N

(c) 245.25N

(d) 1000.0N



Drag

Quiz

A 50kg parachute descends at a steady 40 km/h. What force does the air exert on the parachute?

$\bar{v} = 40\,\mathrm{km/s}$ constant

$\downarrow$

$\bar{a} = 0$

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

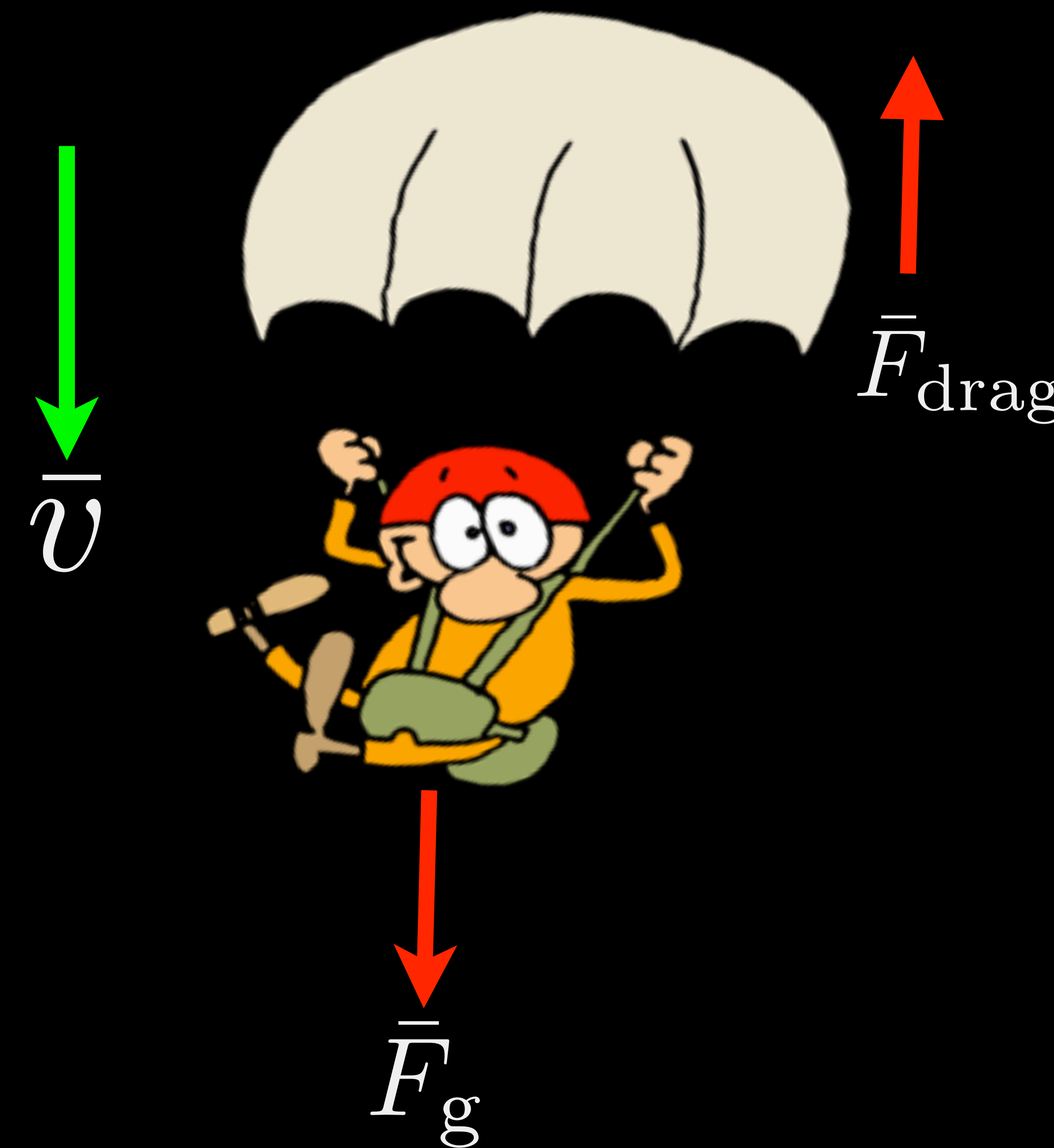
$\bar{F}_{\mathrm{net}} = 0$

$\downarrow$

$$\bar{F}_{\mathrm{drag}} = \bar{F}_g$$

$$= mg = (50\,\mathrm{kg})(9.81\,\mathrm{m/s^2})$$

$$= 490.5\,\mathrm{N}$$



Drag

Quiz

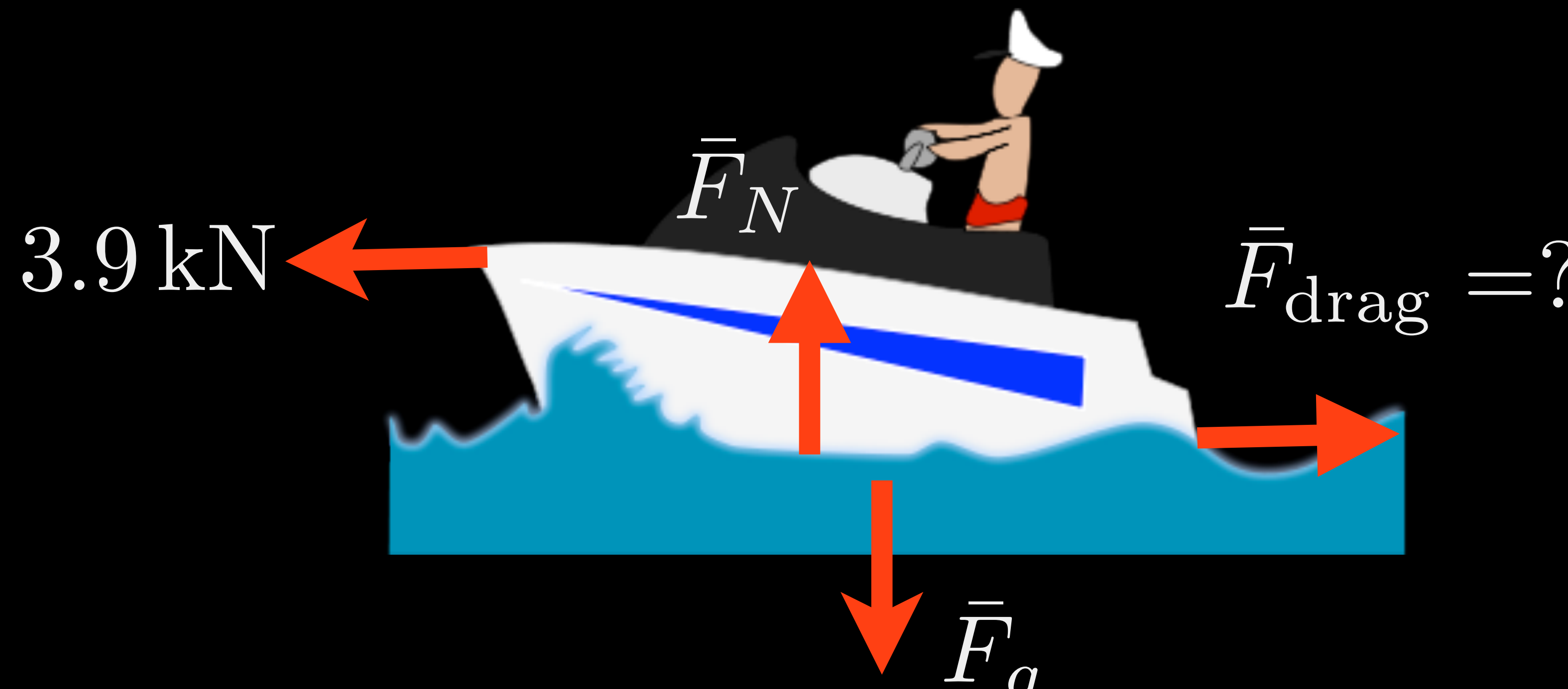
A 930 kg motorboat accelerates away from the dock at 2.3 m/s^2. Its propeller provides a 3.9 kN thrust force. What drag force does the water exert on the boat?

(a) 96.2 N

(b) 5223 N

(c) 1.8 N

(d) 1761 N



Drag

Quiz

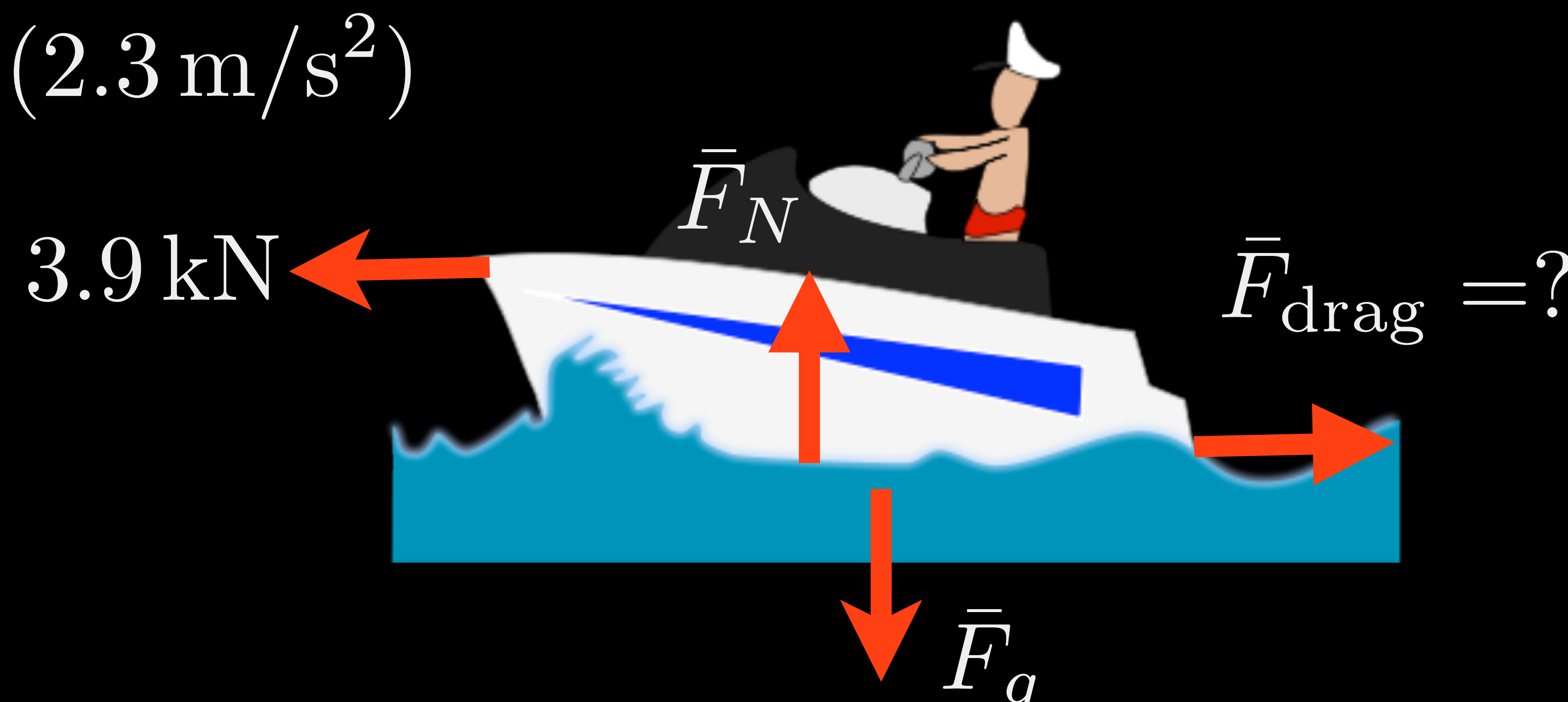
A 930 kg motorboat accelerates away from the dock at 2.3 m/s^2. Its propeller provides a 3.9 kN thrust force. What drag force does the water exert on the boat?

horizontal Newton 2nd: $\bar{F} = m\bar{a}$

$$F_{\text{thrust}} - F_{\text{drag}} = ma$$

$$F_{\text{drag}} = 3900\,\text{N} - (930\,\text{kg})(2.3\,\text{m/s}^2)$$

$$= 1761\,\text{N}$$



Forces

Quiz

A light inextensible (non-elastic) string passes over a smooth pulley which is accelerating vertically upwards at a rate a_0 .

Masses m_1 and m_2 are attached to the ends of the string.

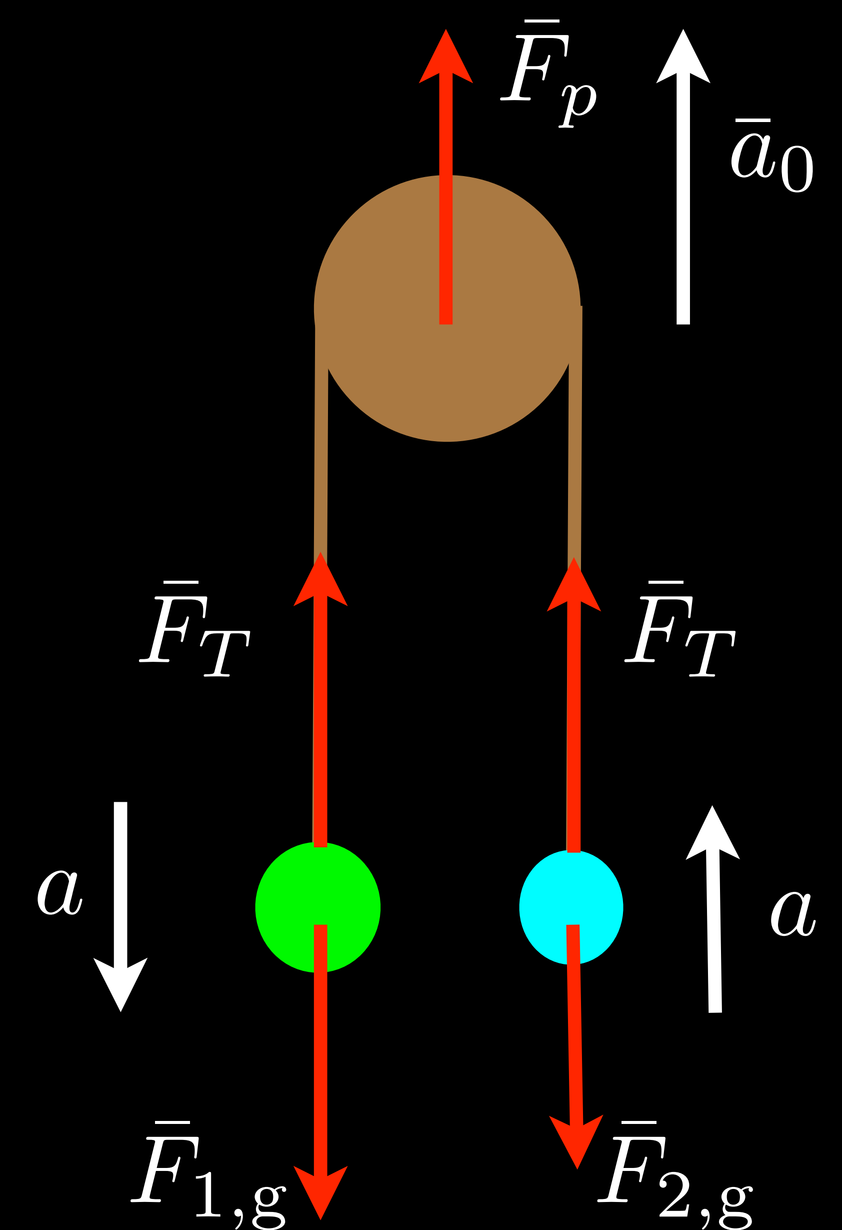
Find the acceleration of the masses.

(a) $a = \frac{2m_1}{a_0 + g}$

(b) $a = (m_1 + m_2)(a_0 + g)$

(c) $a = \frac{(m_2 - m_1)(a_0 + g)}{m_1 + m_2}$

(d) $a = (m_1 + m_2)g$



Forces

Quiz

vertical Newton 2nd: $\bar{F} = m\bar{a}$

Left-hand arm:

$$F_T - F_{1,g} = m_1 a_1$$

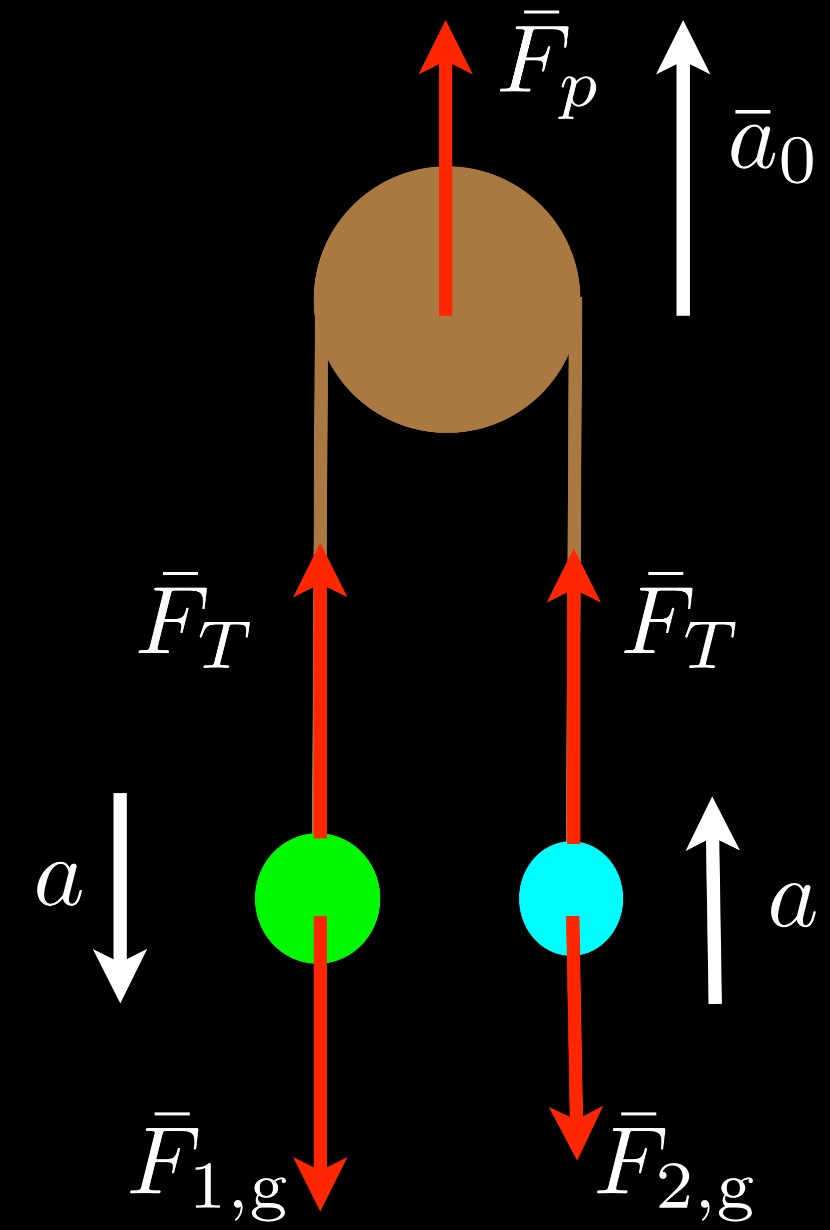
$$F_T = m_1 g + m_1(a_0 - a)$$

Right-hand arm:

$$F_T - F_{2,g} = m_2 a_2$$

$$F_T = m_2 g + m_2(a_0 + a)$$

$$a = \frac{(m_2 - m_1)(a_0 + g)}{m_1 + m_2}$$



Science in the news

Could ‘Planetes’ be real?

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Japan's huge magnetic net will trawl for space junk

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- Magazine issue 2953. **Subscribe and save**
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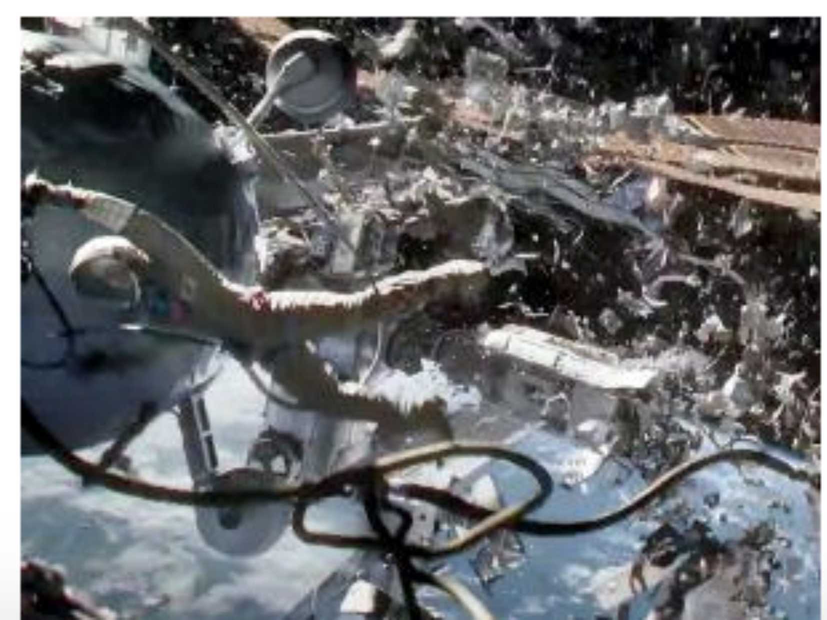
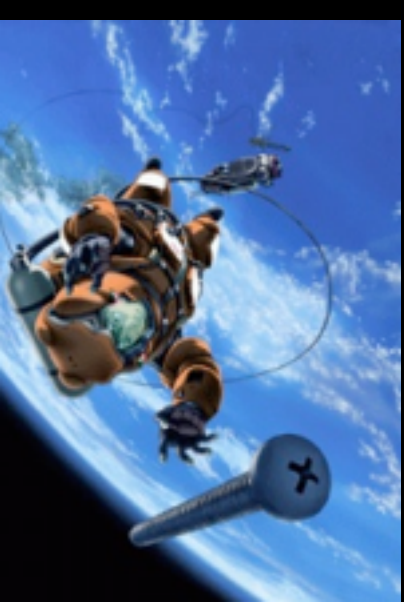
Gravity wasn't all fiction: tiny pieces of high-speed orbiting debris endanger our satellites. Now Japan is set to launch an electromagnetic net to catch them



SOMEWHERE in Earth's orbit, a satellite explodes into a terrifying cloud of debris. Moments later, Sandra Bullock and George Clooney are left scrambling to dodge the deadly space junk. This problem isn't confined to the Oscar-nominated space thriller *Gravity* – scientists are struggling with it in real life. Now a rather unusual solution is being tested: a really big net.

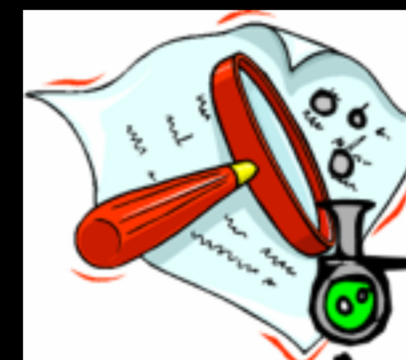
Next month, the Japanese space agency, JAXA, will pilot its "electrodynamic tether" for the first time. It is one of many possible solutions that have been proposed to deal with space debris (see "Catch 'em, drag 'em, blast 'em").

Hundreds of thousands of pieces of spacecraft, satellites and other equipment from human spaceflight zip around our planet, some travelling faster than the speed of sound. According to a report released by the US Congressional



What to look for

WHAT was discovered?

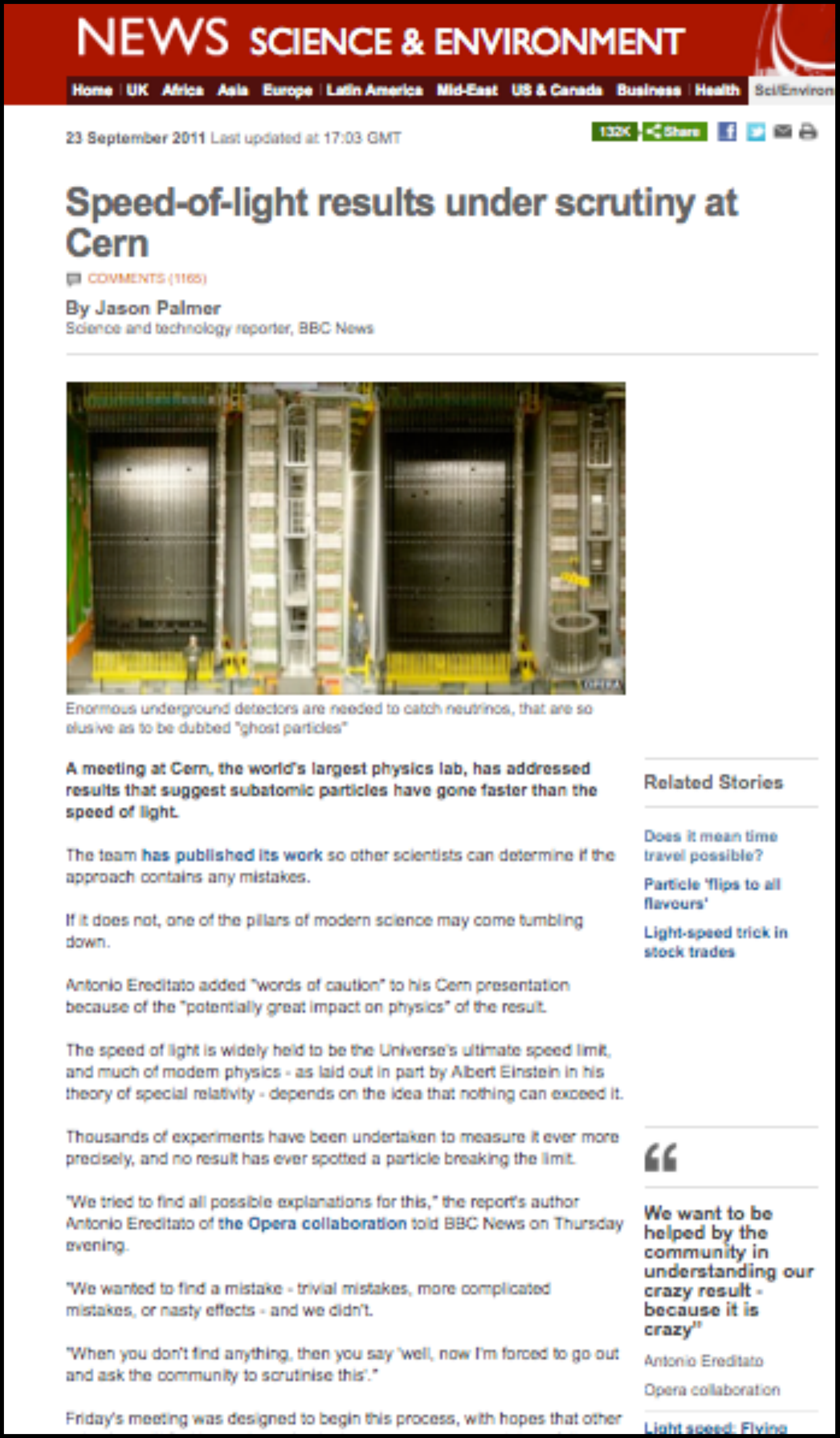


HOW was it done?

WHY is it exciting?

Don’t worry if you cannot understand everything

You only need the big picture



NEWS SCIENCE & ENVIRONMENT

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23 September 2011 Last updated at 17:03 GMT

Speed-of-light results under scrutiny at Cern

COMMENTS (1165)

By Jason Palmer
Science and technology reporter, BBC News

Enormous underground detectors are needed to catch neutrinos, that are so elusive as to be dubbed "ghost particles"

A meeting at Cern, the world's largest physics lab, has addressed results that suggest subatomic particles have gone faster than the speed of light.

The team **has published its work** so other scientists can determine if the approach contains any mistakes.

If it does not, one of the pillars of modern science may come tumbling down.

Antonio Ereditato added "words of caution" to his Cern presentation because of the "potentially great impact on physics" of the result.

The speed of light is widely held to be the Universe's ultimate speed limit, and much of modern physics - as laid out in part by Albert Einstein in his theory of special relativity - depends on the idea that nothing can exceed it.

Thousands of experiments have been undertaken to measure it ever more precisely, and no result has ever spotted a particle breaking the limit.

"We tried to find all possible explanations for this," the report's author Antonio Ereditato of **the Opera collaboration** told BBC News on Thursday evening.

"We wanted to find a mistake - trivial mistakes, more complicated mistakes, or nasty effects - and we didn't.

"When you don't find anything, then you say 'well, now I'm forced to go out and ask the community to scrutinise this'."

Friday's meeting was designed to begin this process, with hopes that other

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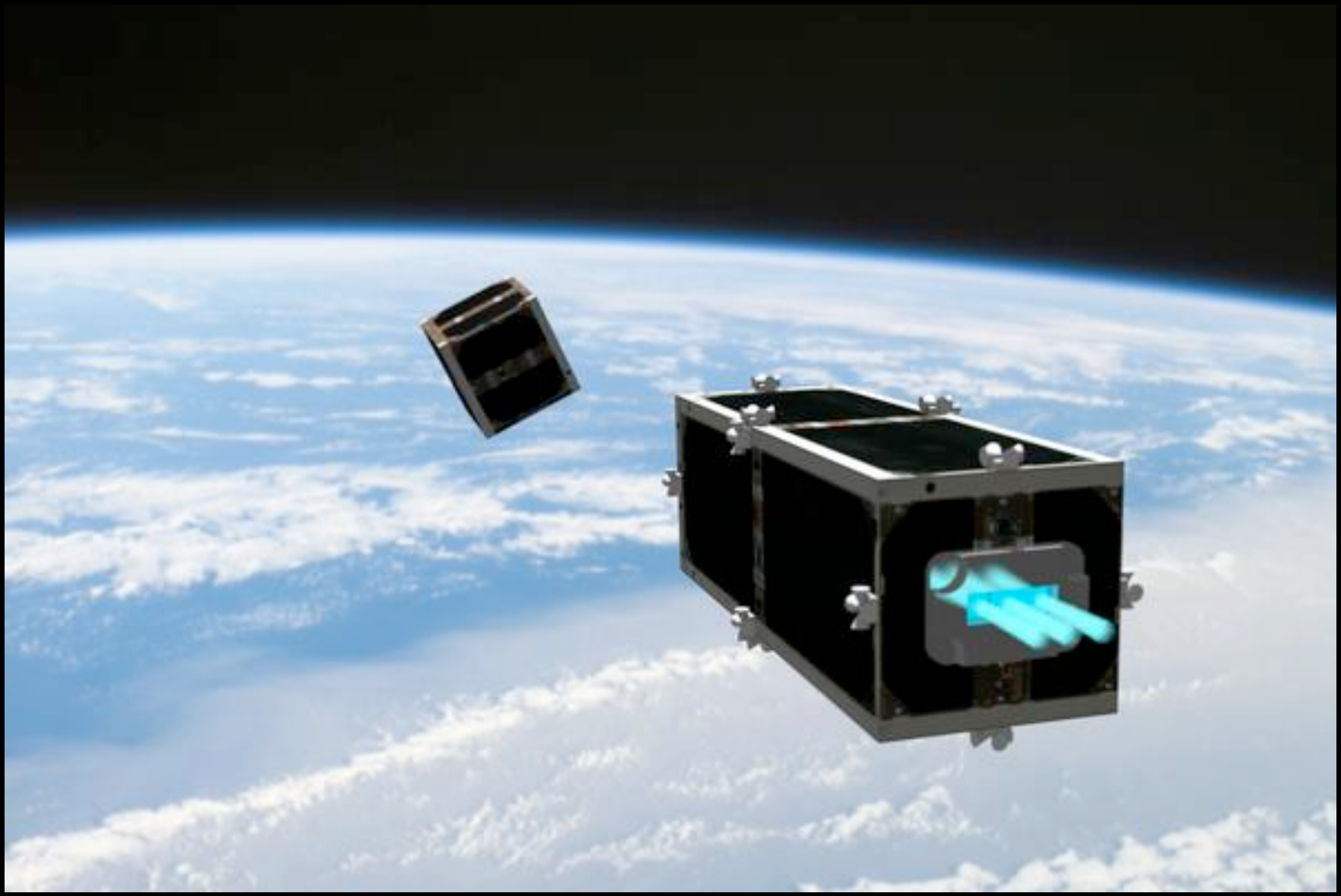
“We want to be helped by the community in understanding our crazy result - because it is crazy”

Antonio Ereditato
Opera collaboration

Light speed: Flying

Science in the news



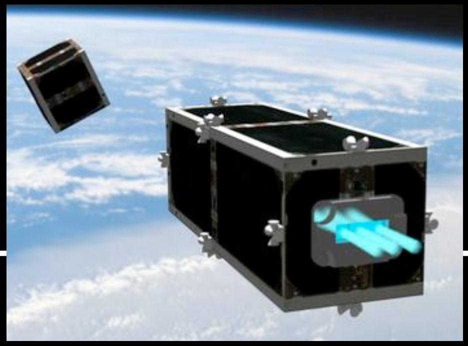
Plans to launch of "*Clean Space 1*"

Science in the news

Launch of *"Clean Space 1"*

Clean Space 1

Quiz



When was the first satellite, Sputnik 1, launched?

(a) 50 years ago

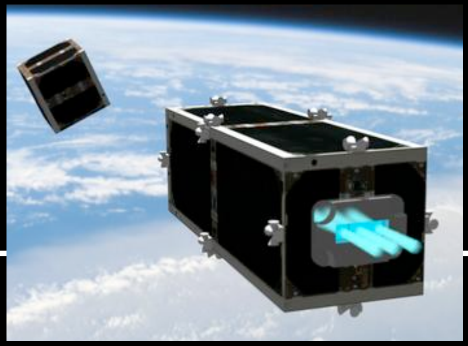
(b) 55 years ago

(c) 57 years ago

(d) 62 years ago

Clean Space 1

Quiz



How many pieces of space debris (garbage) orbit the Earth?

(a) ~ 100,000

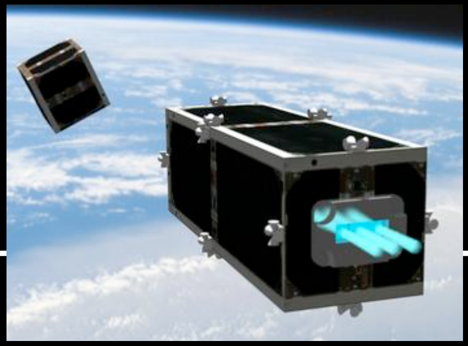
(b) ~ 500,000

(c) ~ 1,000,000

(d) ~ 5,000,000

Clean Space 1

Quiz



Where does space debris come from?

(a) Garbage from the space station

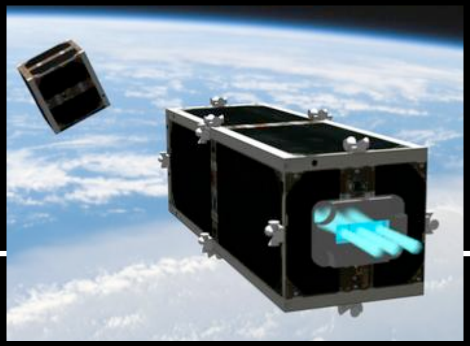
(b) Comets and asteroids from space

(c) Garbage from Earth sent into space

(d) Old rockets and satellites

Clean Space 1

Quiz



Why is there so much space debris?

(a) Space station breaks apart satellites

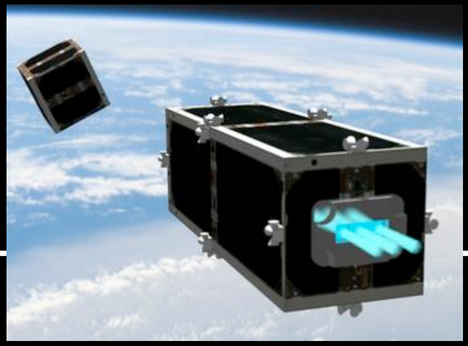
(b) Many satellites launched

(c) Collisions between old satellites make many pieces

(d) The sun’s rays break satellites into pieces

Clean Space 1

Quiz



Why is space debris dangerous?

(a) it can hit current satellites and the space station

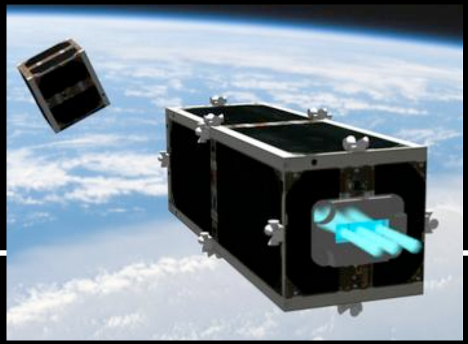
(b) it can block out the sun

(c) it can interfere with TV signals

(d) it can fall to Earth as a big meteor

Clean Space 1

Quiz



How fast does the space debris move?

(a) 10, 000 km/h

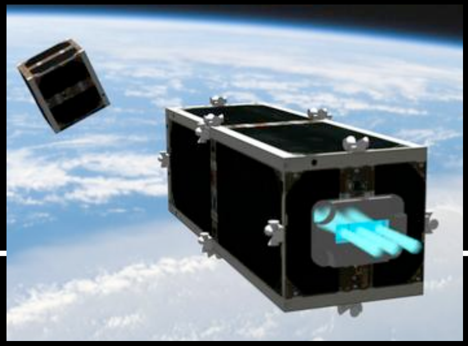
(b) 28,000 km/h

(c) 28,000 m/s

(d) 10,000 light years / month

Clean Space 1

Quiz



When satellites collide, how many pieces of debris can be created?

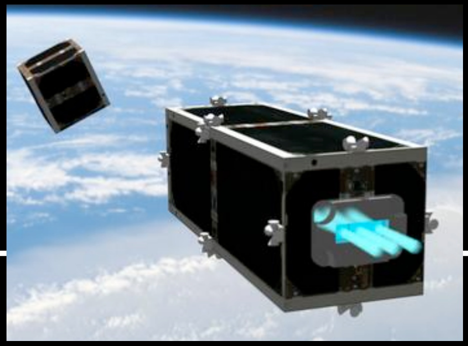
(a) 100

(b) 500

(c) 2000

(d) 100,000

Clean Space 1



How many current satellites are there?

(a) 0.5 million

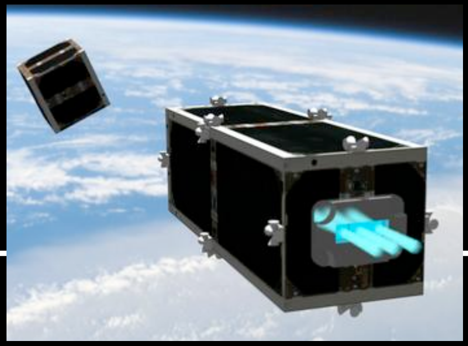
(b) 10,000

(c) 700

(d) 50

Clean Space 1

Quiz



What will 'Clean space 1' do with the old satellites?

(a) Return them to Earth

(b) Destroy them in space

(c) Pull them towards Earth, where the atmosphere will destroy them

(d) Pull them into the Sun, where the heat will destroy them