Chapter 4: Dynamics: Newton's Laws of Motion

4-1 Force
4-2 Newton's First Law of Motion
4-3 Mass
4-4 Newton's Second Law of Motion
4-5 Newton's Third Law of Motion
4-6 Weight—the Force of Gravity; and the Normal Force
4-7 Solving Problems with Newton's Laws: Free-Body Diagrams
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Force (any kind of push or pull on an object)

- Contact forces
- Action at a distance

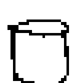
Galileo vs Aristotle

•] **Newton's First Law** is Galileo's conclusion (Law of inertia)

In absence of a net force acting on a body,
{ Body at rest stays at rest
{ Body in motion moves with a constant velocity

Demos: • cork •• tablecloth

Mass = quantity of matter (Newton)
= measure of inertia

SI: 1 kg mass of  Bureau of Weights and Measures   **British** 1 slug ($\approx$ 14.6 kg)

Atomic Mass Unit : 1 u = mass of ^{12}C

Weight: 1 kg weighs $\approx$ 2.2 lb on Earth
0.4 lb on the Moon
6.6 lb on the Jupiter

•] **Newton's Second Law**

$$\vec{a} = \frac{\vec{F}_{net}}{m} \qquad \vec{F}_{net} \equiv \Sigma \vec{F}$$

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} \leftarrow \text{what it is!}$$

$$\vec{a} = \frac{\vec{F}_{net}}{m} \leftarrow \text{how to get it!}$$

$$\vec{F}_{net} = m\vec{a}$$

$$(1\,kg)(1\,m/s^2) \equiv 1\,N$$

• Weight of 1 kg on Earth:

$$W = (1\,kg)(9.81\,m/s^2) = 9.81\,N$$

AMPLES

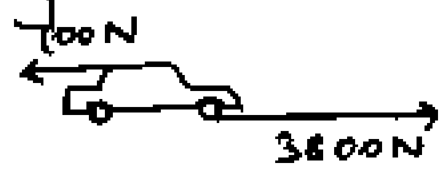
1 Calculate a net force needed to accelerate a 1500 kg car from rest to 80 $^{km}/_{h}$ in 8 seconds at constant a

$$60\frac{km}{h} = 60\ \frac{1000\,m}{3600\,s} = 16.7\ {}^{m}/_{s}$$

$$a = \frac{16.7\ {}^{m}/_{s} - 0}{8\,s} = 2.1\ {}^{m}/_{s^2}$$

$$F^{net} = (1500\ kg)(2.1\ {}^{m}/_{s^2}) \approx 3100\ N$$

If the air resistance is 700 N, then the engine must provide 3800 N



2 The weight of a box is 100 lb. What net force is required to push it with acceleration of $a = 2\ {}^{m}/_{s^2}$?

Method I: 100 lb = 445 N = Weight

$$m = \frac{445\,N}{9.8\ {}^{m}/_{s^2}} = 45\ kg$$

$$F^{net} = (45\ kg)(2\ {}^{m}/_{s^2}) = 90\ N = 20\ lb$$

Method II: If a gravitational force of 100 lb produces $a = 9.8\ {}^{m}/_{s^2}$, then for $a = 2\ {}^{m}/_{s^2}$ you need $100\ lb\ \frac{2}{9.8} \approx 20\ lb$

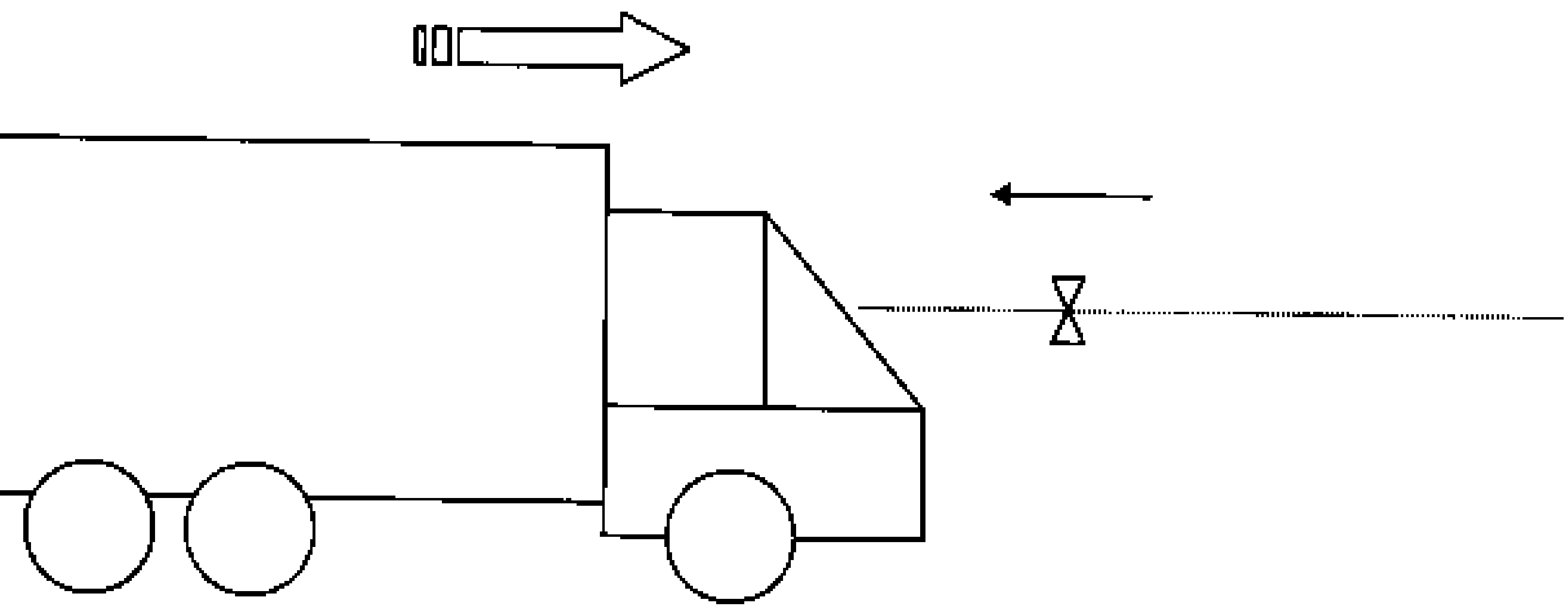
Newton's III LAW

Concept quizzes: Bee & Mack truck, Arnold & Suzie, Gravity

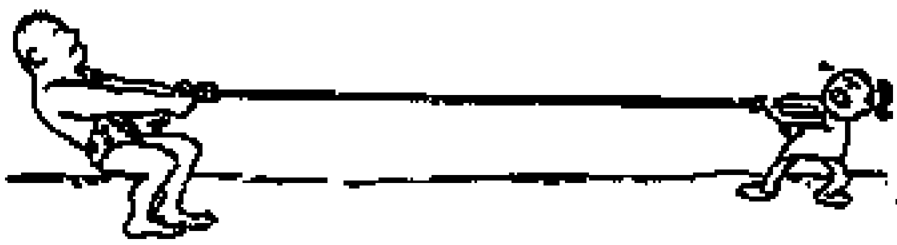
A bee splatters against a windshield of a Mack truck moving at 60 mph. During the collision, the force on a bee is…

Green: larger than…
Yellow: smaller than…
Pink: same as…

the force with which the bee hits the windshield



Arnold and Suzie are having a tug-of-war on a sandy beach. Arnold wins hands down, of course.



Credit: Paul G. Hewitt

Question 1: Who is pulling harder on the rope?

Green: Arnold
Yellow: Suzie
Blue: Both pull the rope with equal forces
Pink: Not enough information given

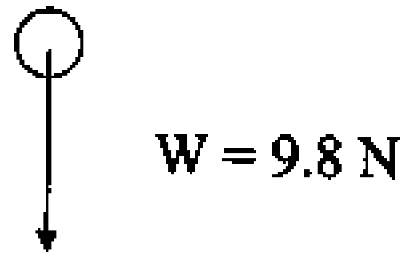
Question 2: Imagine that Arnold and Suzie played the tug-of-war on a very slippery frozen lake. What would happen then?

Green: Arnold won't move but will pull Suzie to his side
Yellow: Suzie won't move but will pull Arnold to her side
Blue: Tie (both will end up moving and meeting somewhere in between)
Pink: Don't know

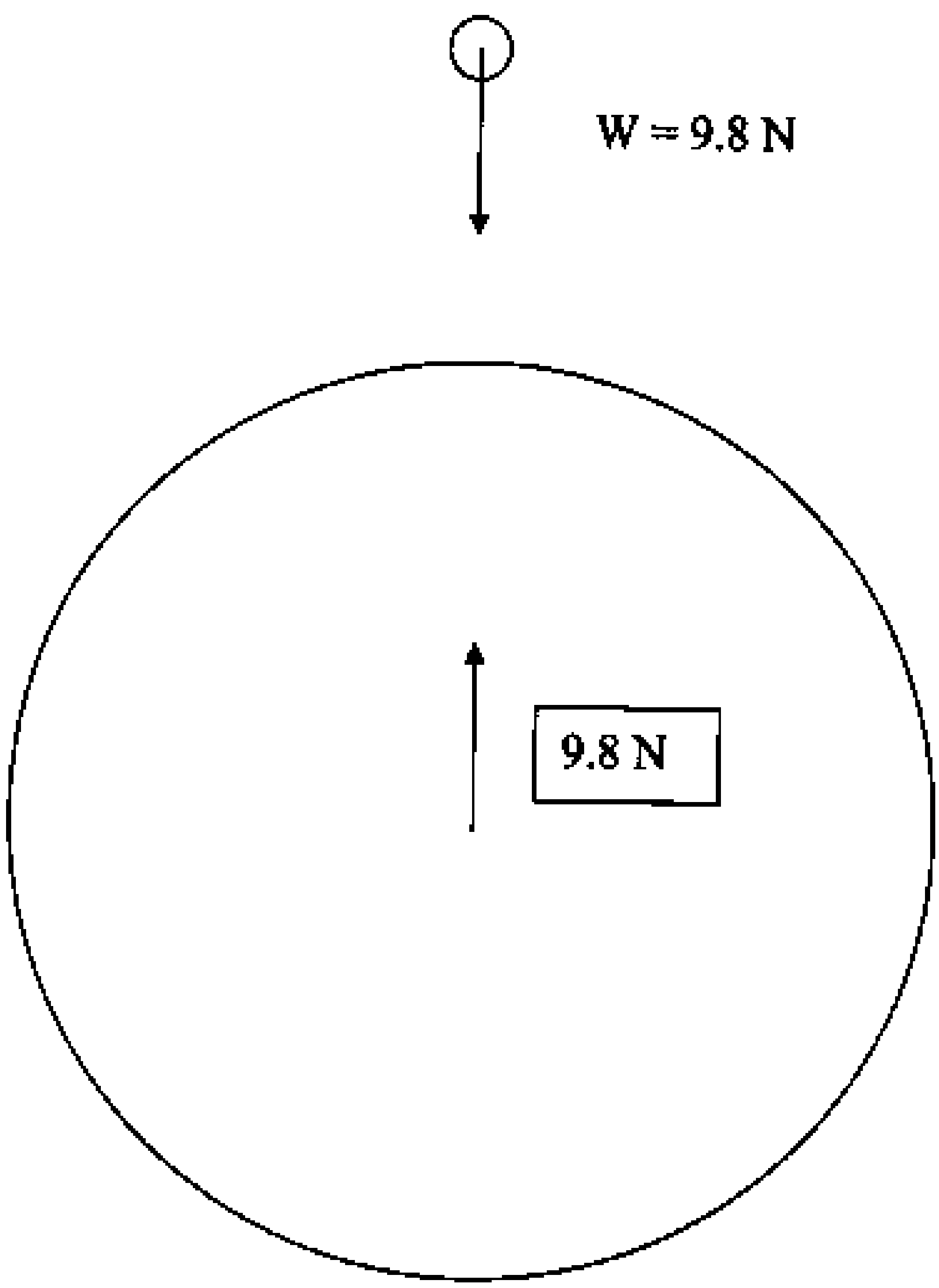
Question 3: (Back to the beach). Who is pushing harder against the sand?

Green: Arnold
Yellow: Suzie
Blue: Both push against the beach with equal forces
Pink: Don't know

A rock of mass m = 1.0 kg is falling under the force of gravity



Considering the pull of gravity an "action", what's the "reaction" force?

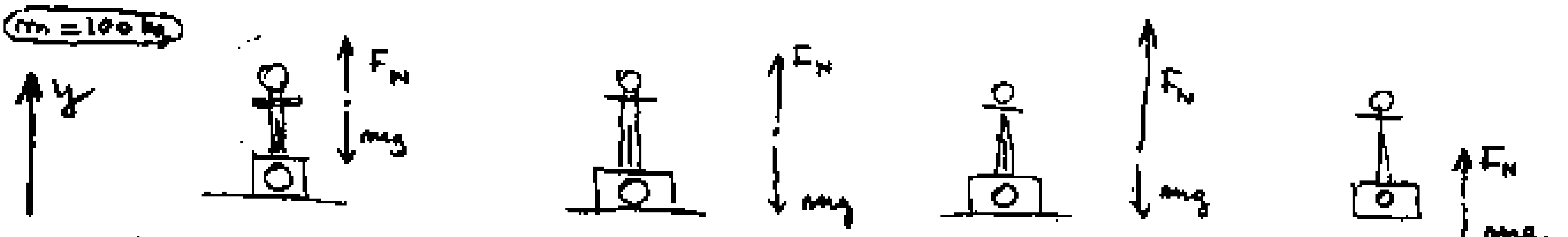


4.6 Weight and the Normal Force

Riding elevators → Concept Quizzes

Calculations:

- Keep in mind that the scale shows a force with which it pushes on the person (by Newton's III Law equal to a push of the person on the scale).
- Reading on the scale is called "apparent weight"



You are at rest

$F_N - mg = 0$

$F_N = mg$

$m = 100$ kg

$F_N = 980$ N

220 lb

You are riding up at 5 m/s (constant velocity)

$F_N - mg = 0$

$F_N = 980$ N

220 lb

You are accelerating upwards at 2 m/s²

$F_N - mg = ma$

$F_N = mg + ma$

$F_N = 980\text{ N} + (100)2$

$F_N = 1180\text{ N} \simeq 265$ lb

You are acc. downwards at $a = -3$ m/s²

$F_N - mg = ma$

$F_N = mg + ma$

$= 980 + 100(-3)$

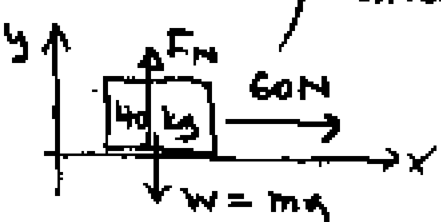
$= 680$ N

$= 153$ lb

Free fall: $F_N - mg = m(-g)$

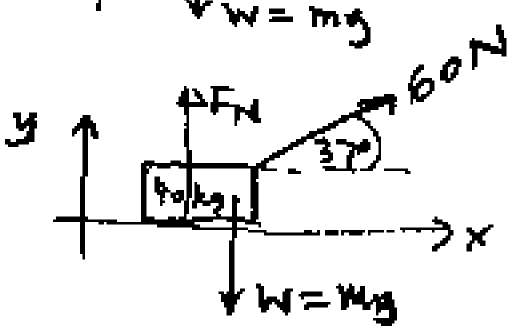
$F_N = 0$ "apparent weight" (reading on the scale) $= 0$

4.7 Free body diagrams



$\Sigma F_x = ma_x$ $\qquad 60\text{ N} = 40\text{ kg} \cdot a_x$ $\qquad \boxed{a_x = 1.5\text{ m/s}^2}$

$\Sigma F_y = 0$ $\qquad F_N - mg = 0$ $\qquad \boxed{F_N = mg = 392\text{ N}}$



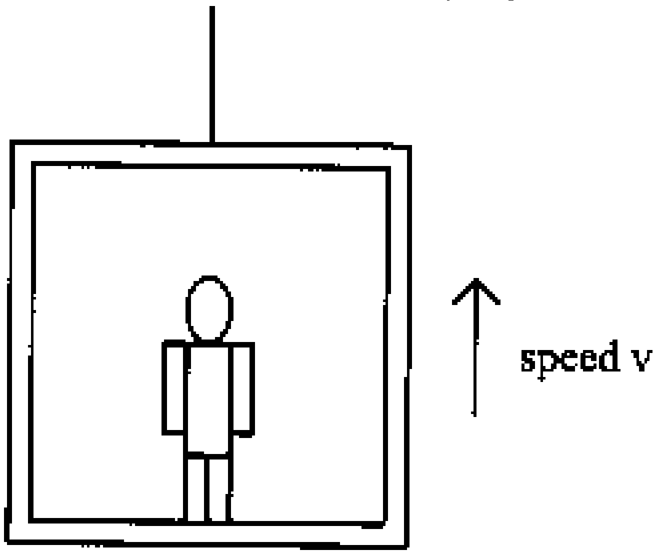
$\Sigma F_x = ma_x$ $\qquad (60\text{ N})\cos 37° = 40\text{ kg} \cdot a_x$ $\qquad \boxed{a_x = 1.2\text{ m/s}^2}$

$\Sigma F_y = 0$ $\qquad F_N + (60\text{ N})\sin 37° - 392\text{ N} = 0$ $\qquad \boxed{F_N = 356\text{ N}}$

Consider a person of weight W standing on a bathroom scale in an elevator that is moving upward at constant speed. What is the reading on the scale?

Blue: larger than W
Pink: the same as W
Yellow: smaller than W but not 0
Green: 0

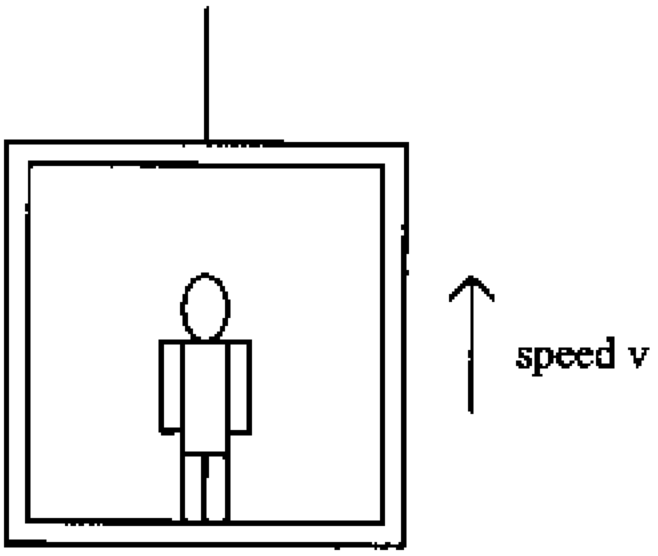
(Note: The reading on the bathroom scale shows the magnitude of the upward normal force, N, exerted by the bathroom scale on the person's feet)



Consider a person of weight 120 lb standing on a bathroom scale in an elevator that just started moving upwards and <u>increases</u> speed at a constant rate. What is the reading on the scale?

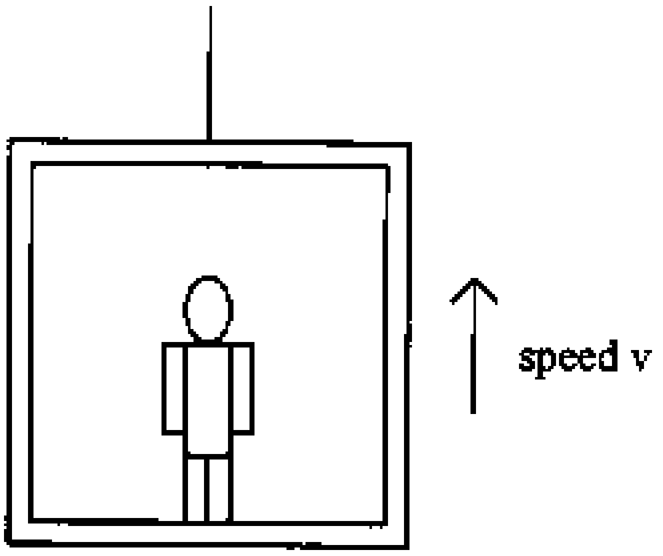
Blue: larger than 120 lb
Pink: 120 lb
Yellow: smaller 120 lb but not 0
Green: 0

(Note: The reading on the bathroom scale (the "apparent weight") shows the magnitude of the upward normal force, N, exerted by the bathroom scale on the person's feet)



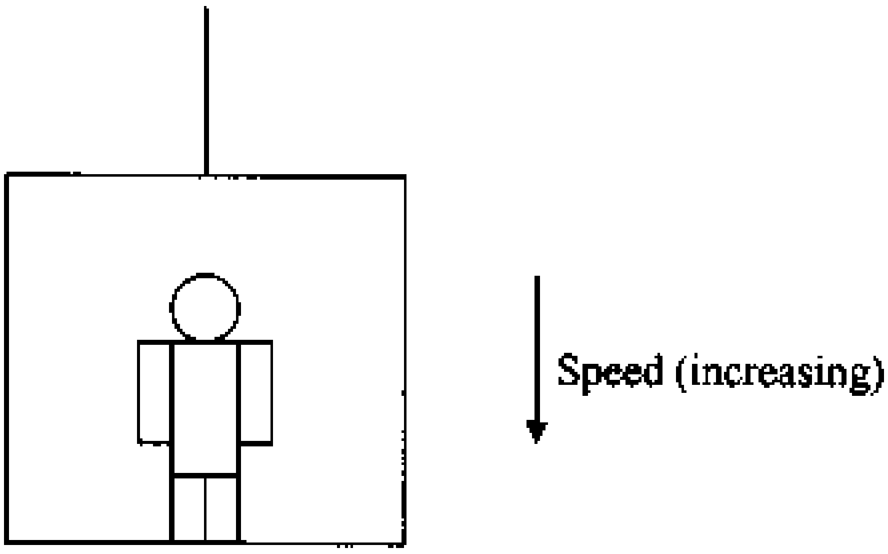
onsider a person of weight 120 lb standing on a bathroom scale in an elevator that is oving up and approaching the final destination, so it slows down, decreasing its eed at a constant rate. What is the reading on the scale (the "apparent weight")?

Blue: larger than 120 lb
Pink: 120 lb
Yellow: smaller 120 lb but not 0
Green: 0



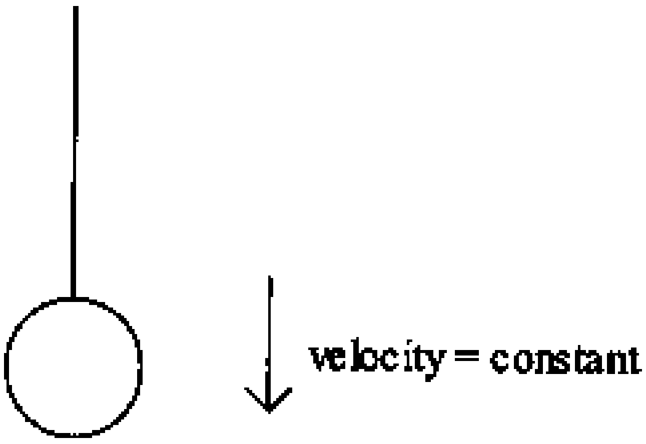
Consider a person of weight 120 lb standing on a bathroom scale in an elevator that just started moving down and increases speed at a constant rate. What is the reading on the scale (the "apparent weight")?

Blue: larger than 120 lb
Pink: 120 lb
Yellow: smaller 120 lb but not 0
Green: 0



6/5

A ball of mass m is being lowered on a cord at a constant speed.
How does the tension T in the cord compare to the weight mg of the object?



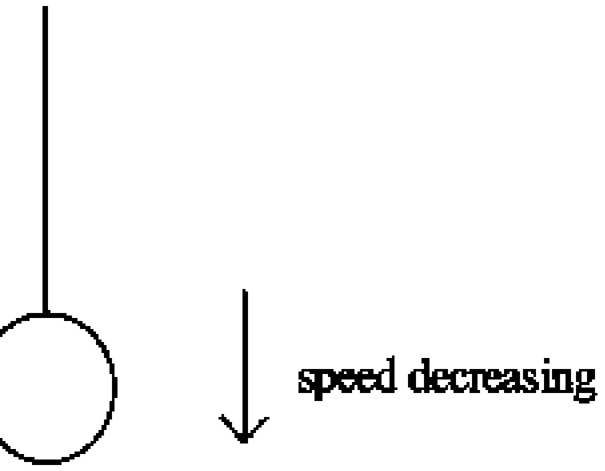
Pink: $T = 0$

Blue: $T = mg$

Yellow: $T > mg$

Green: $T < mg$

n object is being lowered on a cord at a speed which is decreasing. There are two orces on the object, the weight, magnitude mg, and the tension, magnitude T, in e cord. 6/6

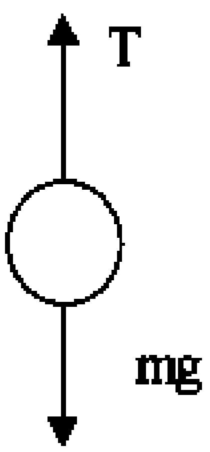


Question: Which equation is true?

Blue: T = mg

Yellow: T > mg

Green: T < mg



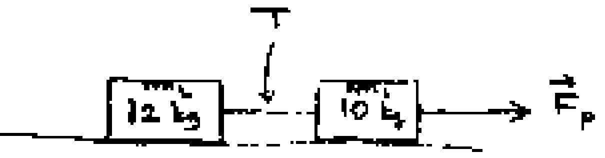
Hint: What is the direction of the acceleration?

Pink: up

Yellow: down

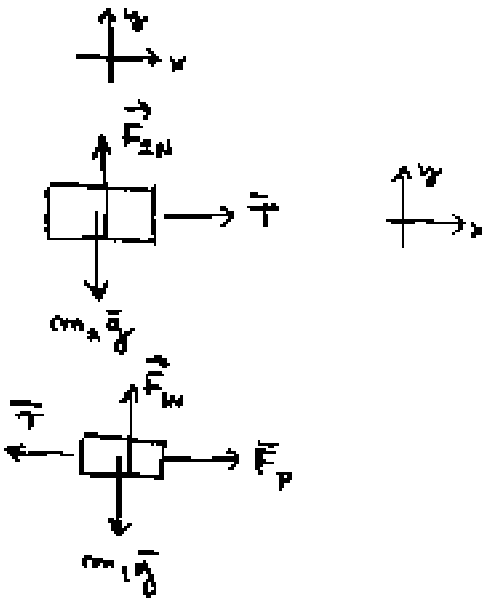
Green: a=0

Example



$F_p = 40\ N$

a) Find acceleration



$\Sigma F_x = m_2 a_x \rightarrow \quad T = m_2 a$ $\rightarrow T = (12\,kg)(1.8\,m/s^2)$, $\boxed{T = 22\ N}$

$\Sigma F_x = m_1 a_x \rightarrow \quad F_p - T = m_1 a$

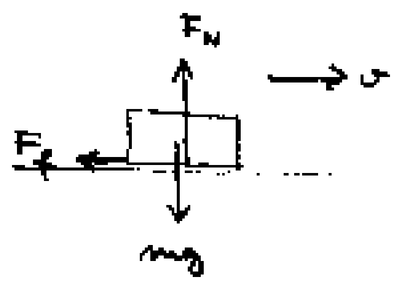
$F_p = (m_1 + m_2) a$

$a = \frac{F_p}{m_1 + m_2} = \frac{40\,N}{10\,kg + 12\,kg} = \boxed{1.8\,m/s^2}$

Demo (1K20.15)

4.8 Friction

- Kinetic friction $\quad F_f = \mu_k F_N$

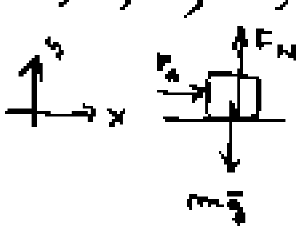


- Static friction $\quad F_f \leq \mu_s F_N$

Push the block with increasing force

EX 4-12

A 10 kg block sits on the horizontal floor, $\mu_s = 0.40$, $\mu_k = 0.30$. Determine F_f and acceleration if one pushes horizontally with $F_A =$ $= 0, 10, 20, 38, 40\ N$



"y" $\quad F_N - mg = 0 \quad F_N = mg = (10\,kg)(9.8\,m/s^2) = 98\ N$

Therefore $\mu_s F_N = (0.40)(98\,N) = \boxed{39.2\,N}$ ← max. static

So: $F_A = 0 \quad F_f = 0$

$F_A = 10\,N \quad F_f = 10\,N$

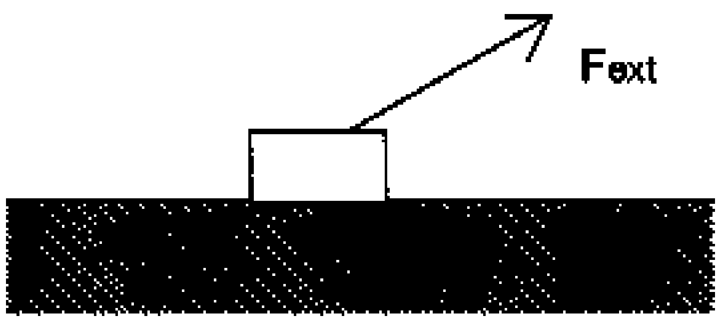
$F_A = 20\,N \quad F_f = 20\,N$

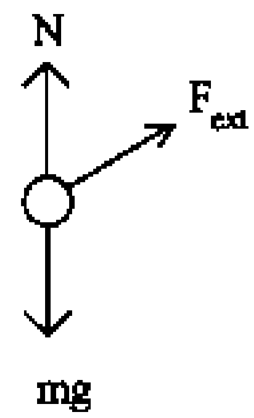
$F_A = 38\,N \quad F_f = 38\,N$

$F_A = 40\,N$, object starts moving. $F_f = (0.3)(98\,N) = 29\ N$ (← kinetic!)

$F_A - F_f = ma \qquad (40\,N) - (29\,N) = (10\,kg)\,a \longrightarrow \boxed{a = 1.1\,m/s^2}$

A mass m is pulled along a frictionless table by a <u>constant</u> external force F_{ext} at some angle above the horizontal. The magnitudes of the forces on the free-body diagram have not been drawn carefully, but the directions of the forces are correct.





Which statement below is true?

Blue:	$N < mg$
Green:	$N > mg$
Yellow:	$N = mg$

32. FBD \ fbd-friction

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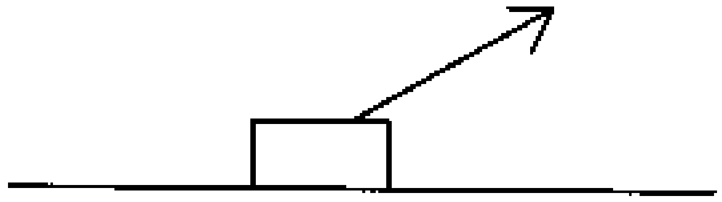
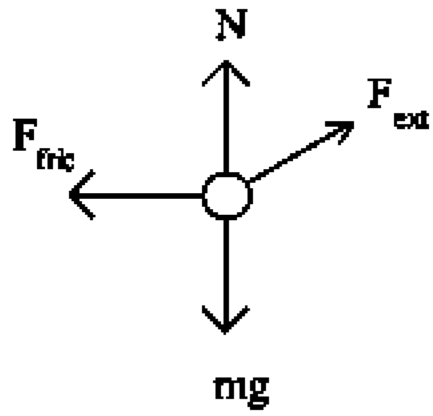
A mass m is pulled along a rough table at <u>constant</u> velocity with an external force F_{ext} at some angle above the horizontal. The magnitudes of the forces on the free-body diagram may not have been drawn carefully, but the directions of the forces are correct.

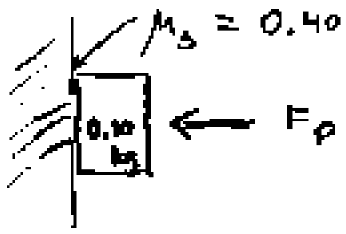




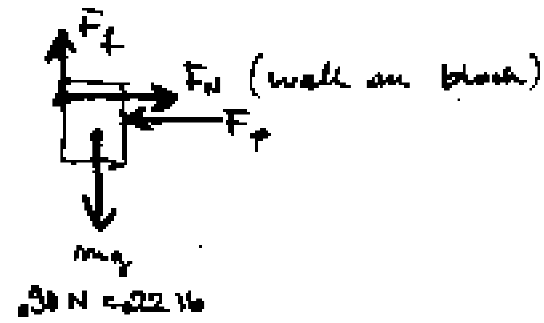
Which statement below is true?

Blue:	$F_{fric} > F_{ext}$, $N > mg$.
Green:	$F_{fric} < F_{ext}$, $N < mg$.
Yellow:	$F_{fric} > F_{ext}$, $N < mg$.
Pink:	$F_{fric} < F_{ext}$, $N > mg$.
Purple:	None of these.

Push an eraser against the wall



How hard do I have to push to keep it in place?



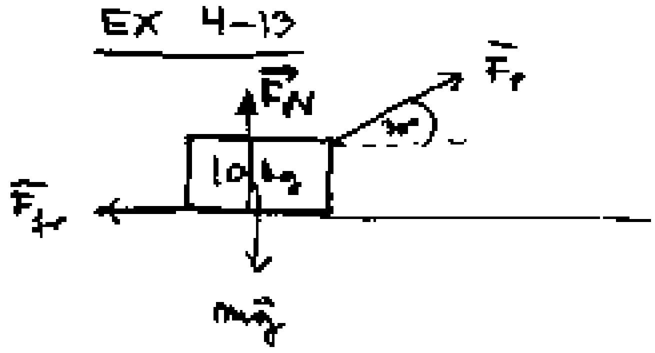
• ΣF_x: $F_N - F_p = 0$ $\quad F_N = F_p$

$F_f = \mu_s F_N = \mu_s F_p$

• ΣF_y: $mg - \mu_s F_p = 0 \rightarrow F_p = \frac{mg}{\mu_s} = \frac{(.10)(9.8)}{0.4}$

$= 2.45 N$

EX 4-13



$\mu_k = 0.30$

$F_p = 40 N$

"x"] $F_p \cdot \cos 30° - F_f = ma_x$

but $F_f = \mu_k F_N$

$F_p \cos 30° - \mu_k F_N = ma_x \rightarrow a_x = \frac{F_p \cos 30° - \mu_k F_N}{m}$

"y"] $F_N + F_p \sin 30° - mg = ma_y = 0$

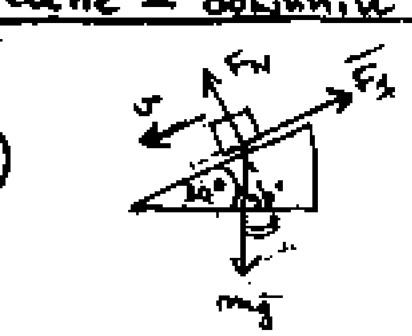
$F_N = mg - F_p \sin 30° = (10)(9.8) - 40(0.5) = 78 N$

$a_x = \frac{(40N)(0.87) - 0.30(78N)}{10 kg} = 1.1 m/s^2$

Concept quizzes → 7/0

Demo 1253

Incline – downhill skiing



$\theta = 30°$

$\mu_k = 0.10$

•] Find acceleration

• We know skier is already sliding down.

"x" $mg \sin\theta - F_f = ma_x \rightarrow a_x = \frac{mg \sin\theta - \mu_k F_N}{m}$

$F_f = \mu_k F_N$

"y" $F_N - mg \cos\theta = 0 \longrightarrow F_N = mg \cos\theta$

$a_x = \frac{mg \sin\theta - \mu_k mg \cos\theta}{m}$

$$\boxed{a_x = (\sin\theta - \mu_k \cos\theta) g}$$ [mass-independent!]

$a_x = [0.5 - (0.10)(0.866)] g = 0.41 g = 4.0 m/s^2$

Mass independent – (Demo) (1K20.35)

Note: if sliding up, force of friction is down $\quad a_x = g(\sin\theta + \mu_k \cos\theta)$