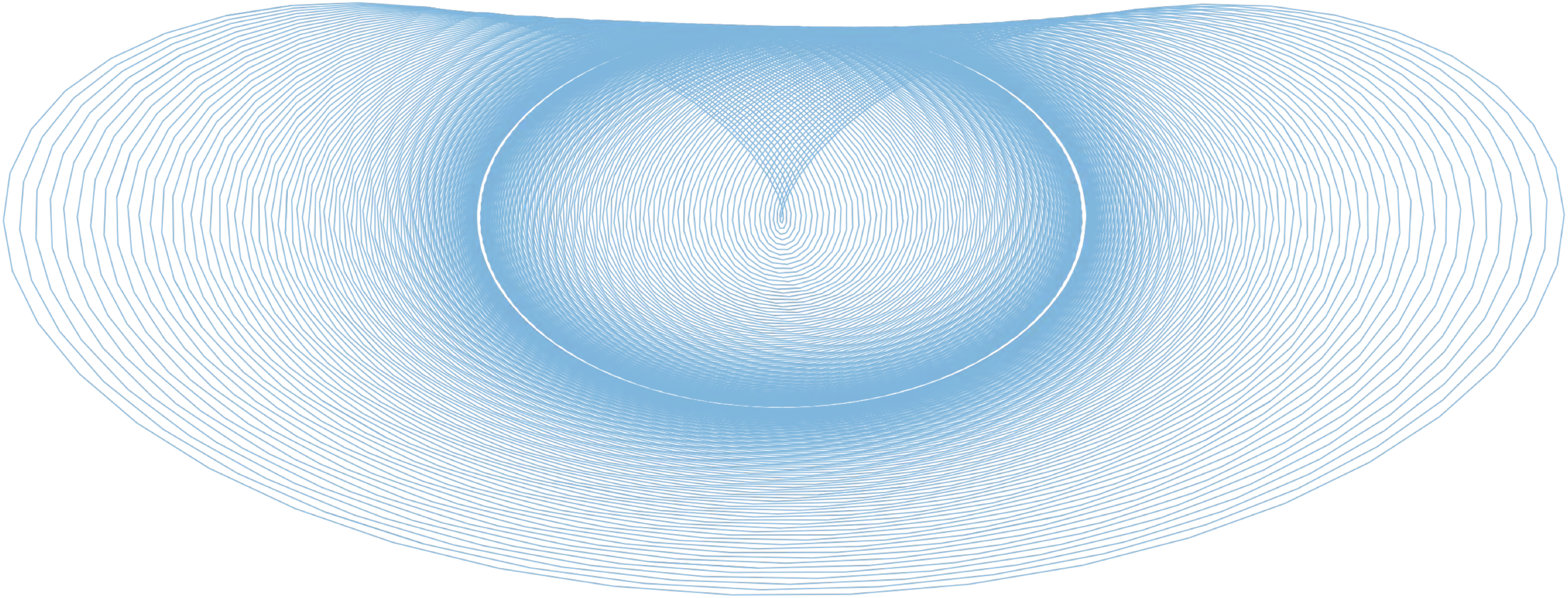
PHYS 1420 (F19)
Physics with Applications to Life Sciences



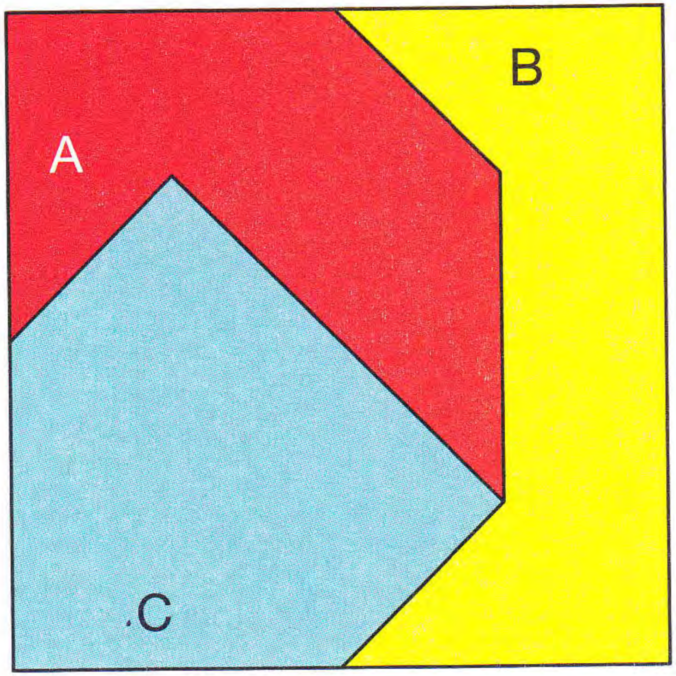
2019.09.25

Relevant reading:
Kesten & Tauck ch.4.6

Christopher Bergevin
York University, Dept. of Physics & Astronomy
Office: Petrie 240   Lab: Farq 103
cberge@yorku.ca

Ref. (re images):
Wolfson (2007), Knight (2017)

65. Square Areas



Which section has the greatest area (or are they equal)?

A

B

C

Equal

Announcements & Key Concepts (re Today)

→ Online HW #4: Posted and due Wednesday 10/2

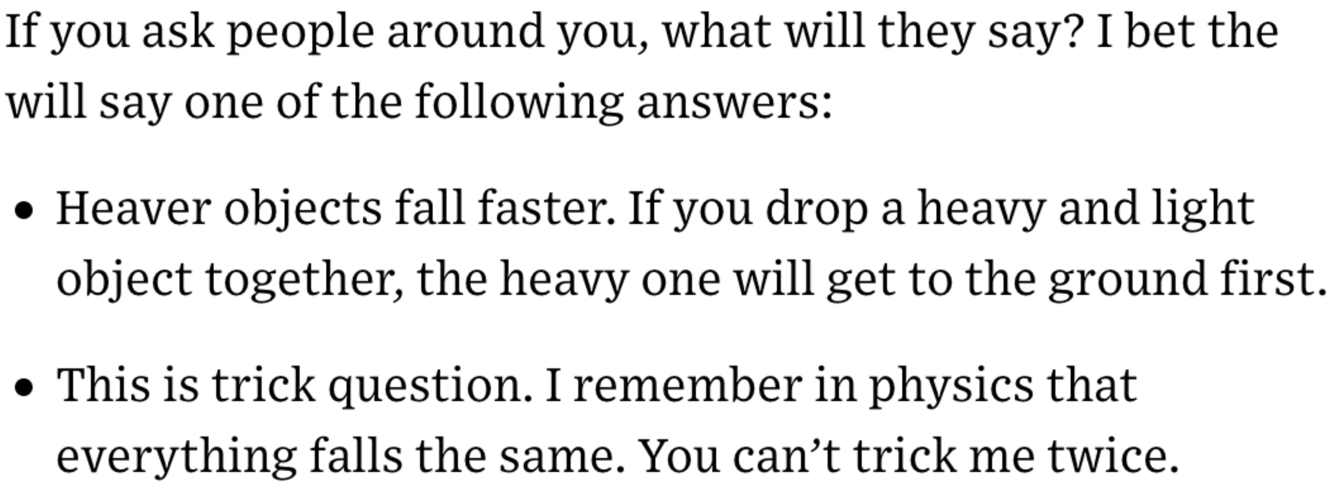
→ Written HW #1 due TODAY (at stat of class)

Some relevant underlying concepts of the day…

- ➢ Normal forces
- ➢ Reference frames
- ➢ Examples (e.g., “birds on a lorry”)

Ex.

If I drop a bowling ball, a spoon, and a book at the same time from the same height, do they fall at the same rate?



If you ask people around you, what will they say? I bet the will say one of the following answers:

- Heaver objects fall faster. If you drop a heavy and light object together, the heavy one will get to the ground first.
- This is trick question. I remember in physics that everything falls the same. You can’t trick me twice.

https://www.wired.com/2013/10/do-heavier-objects-really-fall-faster/

Ex. (SOL)

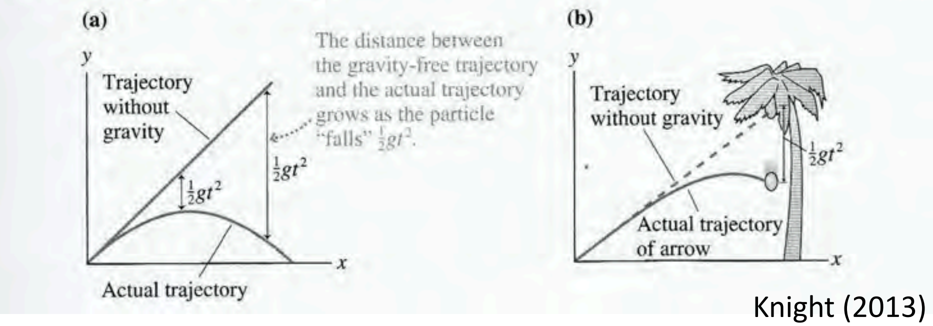
If I drop a bowling ball, a spoon, and a book at the same time from the same height, do they fall at the same rate?

→ No (e.g., consider our feather from before). But only for reasons we have not yet discussed.

→ But if we did it in vacuum, then yes because:

- Heavier objects experience a larger gravitational force...
  (force is proportional to mass)
- ... which is offset by the higher mass (acceleration is inversely proportional to mass)
- In the end, mass doesn't influence the acceleration due to gravity (hence 9.81 m/s^2 applies to everything, in principle)

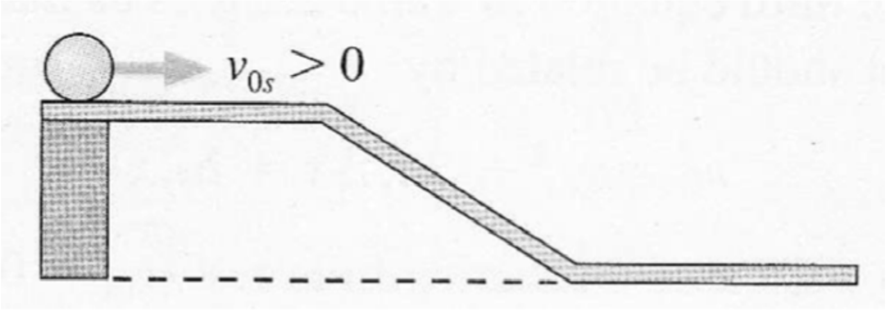
FIGURE 4.18 A projectile follows a parabolic trajectory because it "falls" a distance $\frac{1}{2}gt^2$ below a straight-line trajectory.



Knight (2013)

Ex.

From earlier....



Our ball on the track is a bit different. Why?

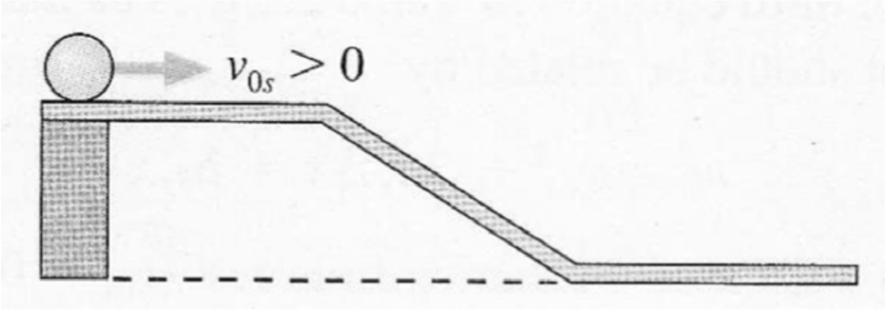
(we’ll come back to this now)

→ We treat it as a 1-D problem rather than a 2-D one. Why?

→ Put another way, why doesn’t the ball fall through the track?

Ex. (SOL)

From earlier....

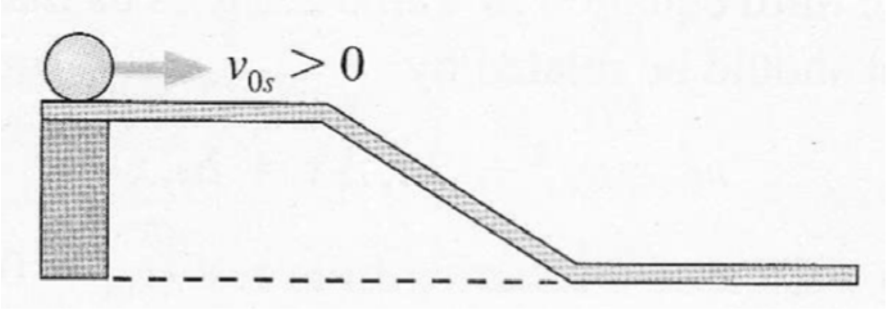


Our ball on the track is a bit different. Why?
(we'll come back to this now)

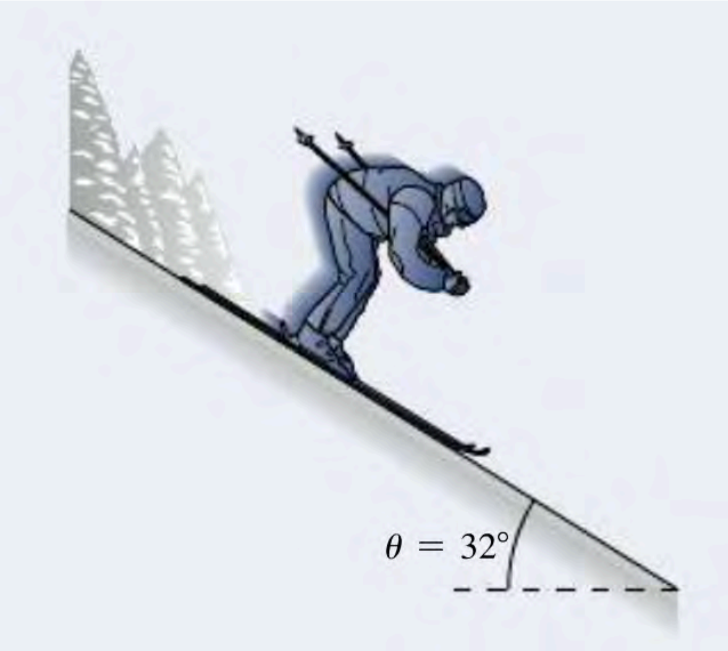
- That really is a 2-D problem
- Only becomes a 1-D problem once all the relevant force are determined
- Consider not just gravity, but also the force the track exerts (i.e., "normal" force). Put another way, the ball is "constrained"
- There are always forces acting on the ball....
- ... but changes in motion stem from non-zero net forces
- Also at play here is the periods of uniform and non-uniform motion

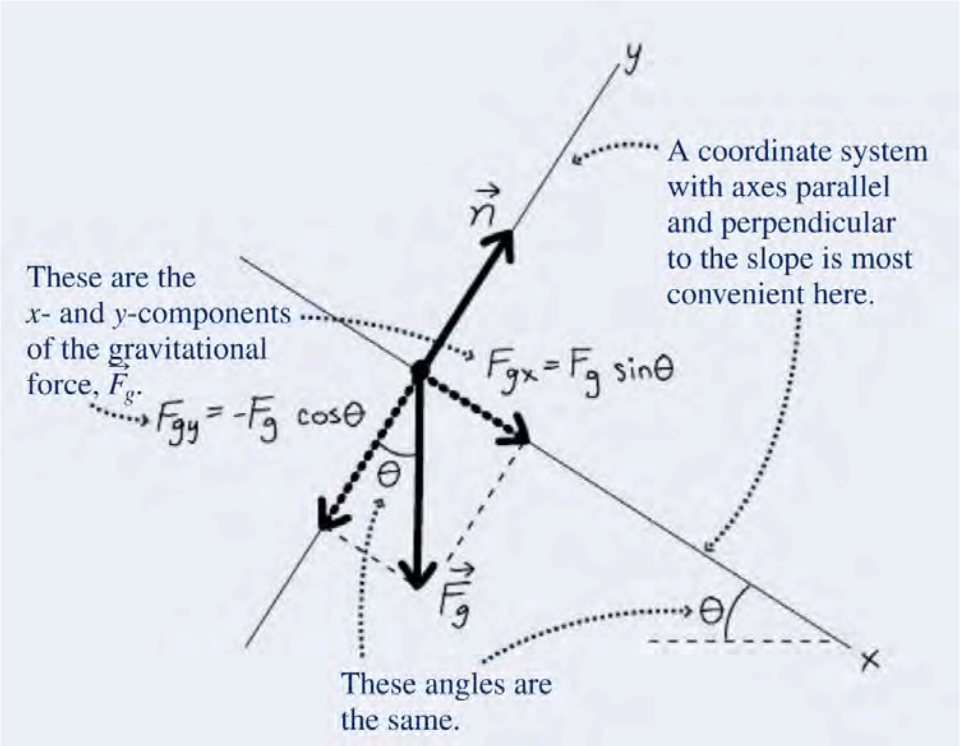
Normal Force

- So what keeps the ball from falling through the track?



→ The track must provide some “counter” (or “contact”) force....





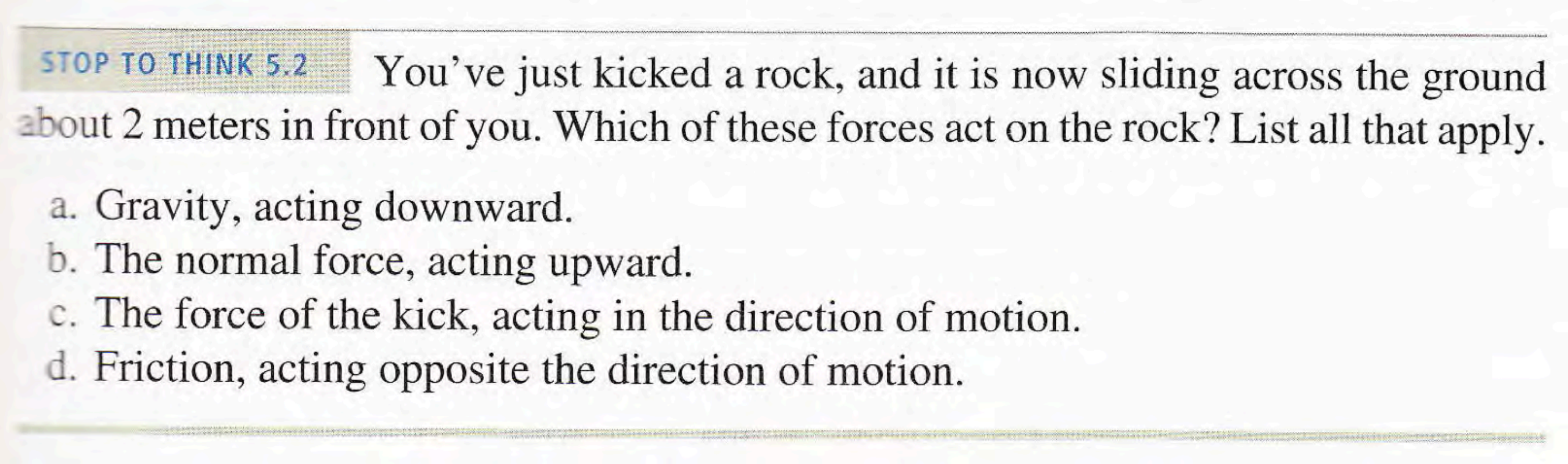
A coordinate system with axes parallel and perpendicular to the slope is most convenient here.

These are the *x*- and *y*-components of the gravitational force, $\vec{F}_g$.

These angles are the same.

Wolfson

Ex.

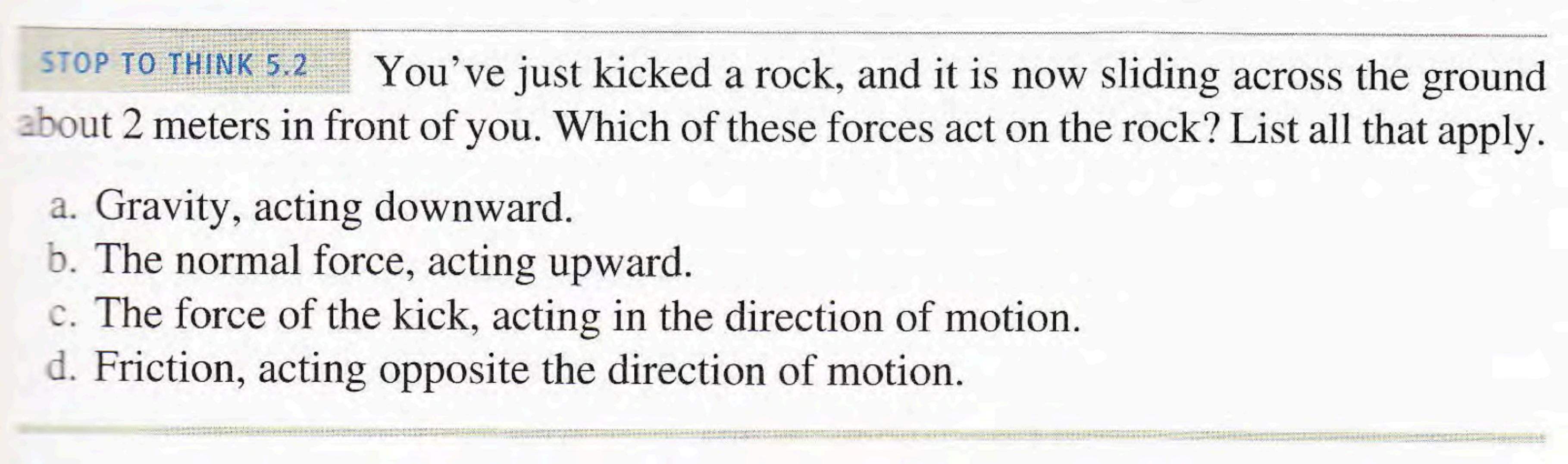


STOP TO THINK 5.2 You've just kicked a rock, and it is now sliding across the ground about 2 meters in front of you. Which of these forces act on the rock? List all that apply.

a. Gravity, acting downward.
b. The normal force, acting upward.
c. The force of the kick, acting in the direction of motion.
d. Friction, acting opposite the direction of motion.

Knight (2013)

Ex. (SOL)



STOP TO THINK 5.2 You've just kicked a rock, and it is now sliding across the ground about 2 meters in front of you. Which of these forces act on the rock? List all that apply.

a. Gravity, acting downward.
b. The normal force, acting upward.
c. The force of the kick, acting in the direction of motion.
d. Friction, acting opposite the direction of motion.

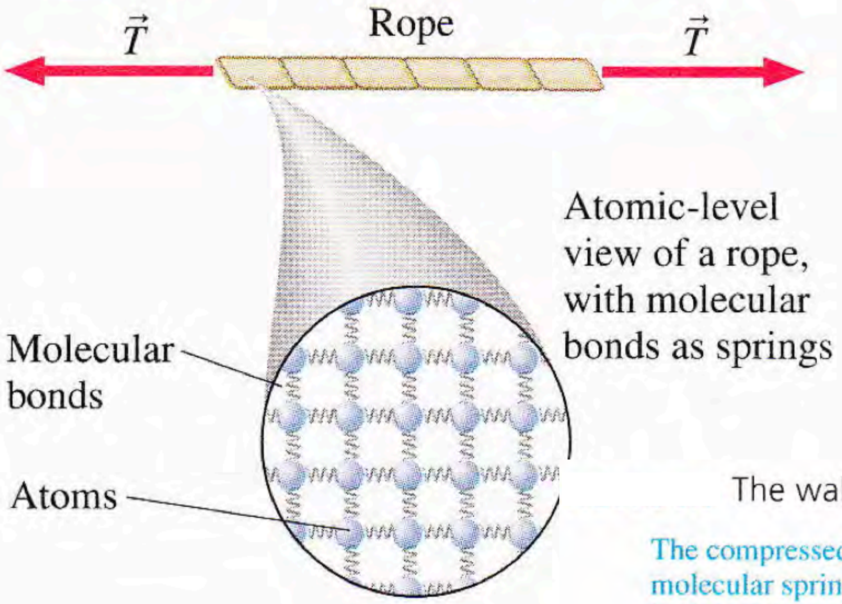
a, b, & d

Knight (2013)

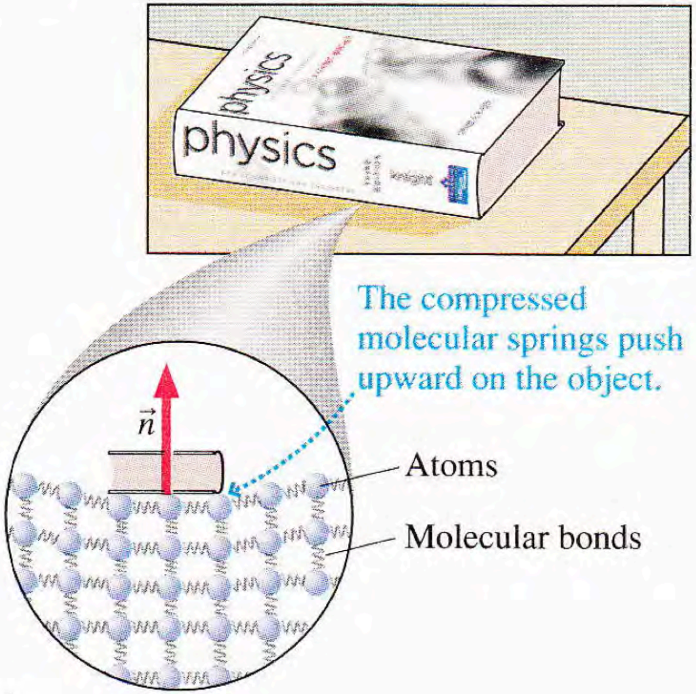
Normal Forces: Rigid vs Stretch-y

- How these counter forces relate to the "fundamental" forces?

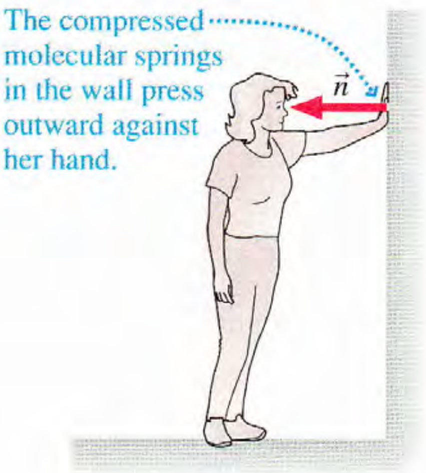
An atomic model of tension.



An atomic model of the force exerted by a table.

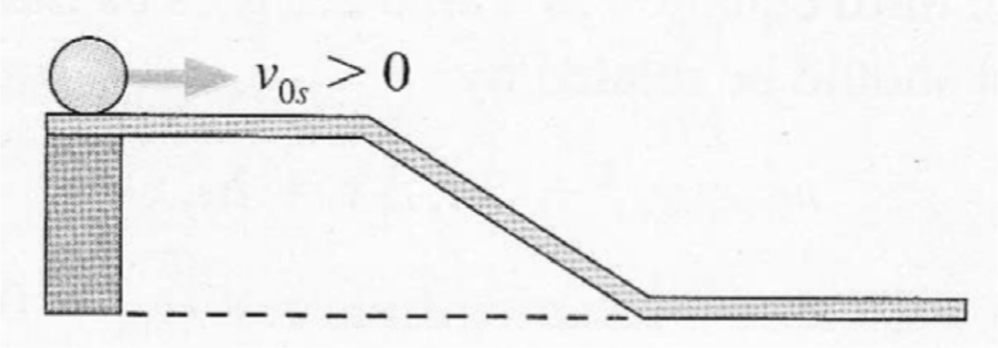


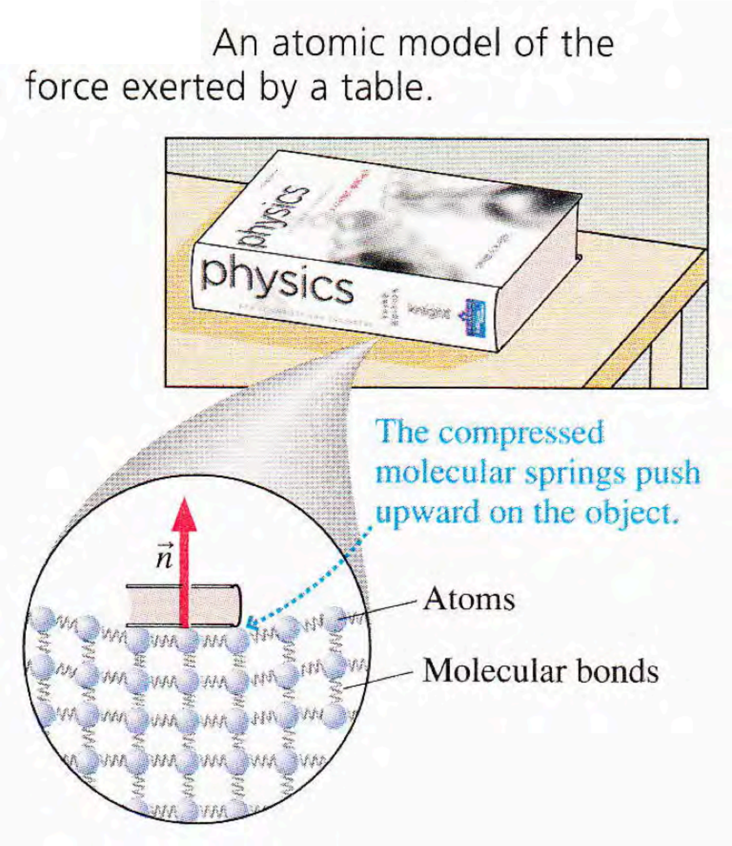
The wall pushes outward.



Knight (2013)

Normal Forces: Rigid vs Stretch-y

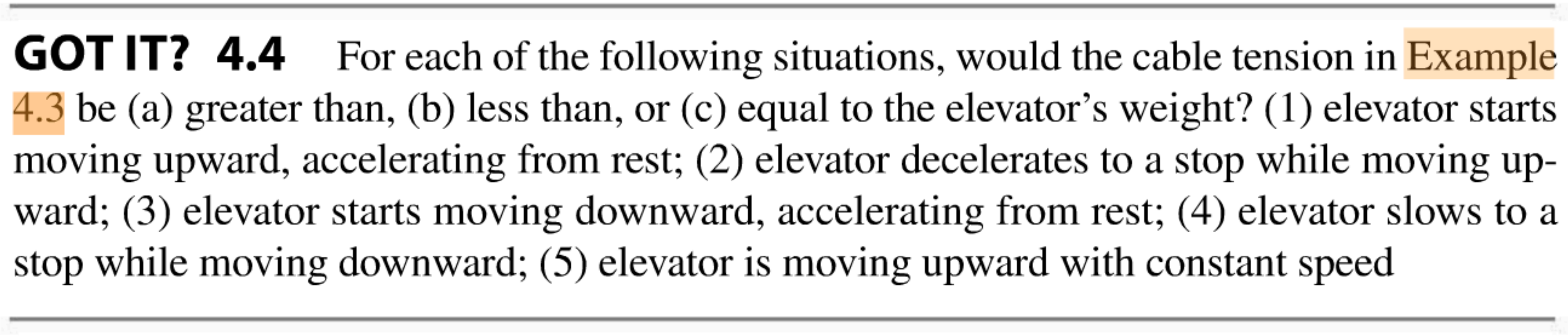



An atomic model of the force exerted by a table.

→ So similar forces are at play here re these two scenarios

(electromagnetic and gravitational forces)

Ex.



GOT IT? 4.4 For each of the following situations, would the cable tension in Example 4.3 be (a) greater than, (b) less than, or (c) equal to the elevator's weight? (1) elevator starts moving upward, accelerating from rest; (2) elevator decelerates to a stop while moving upward; (3) elevator starts moving downward, accelerating from rest; (4) elevator slows to a stop while moving downward; (5) elevator is moving upward with constant speed

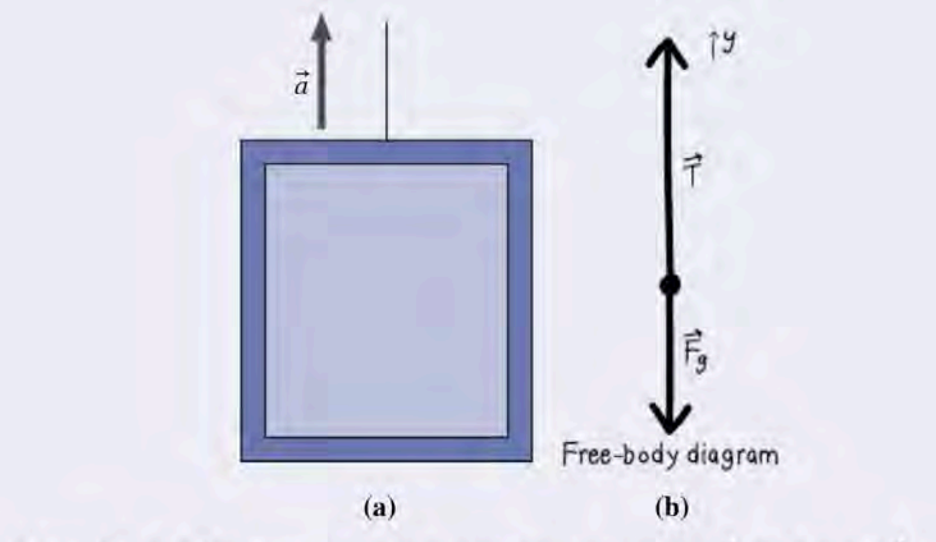
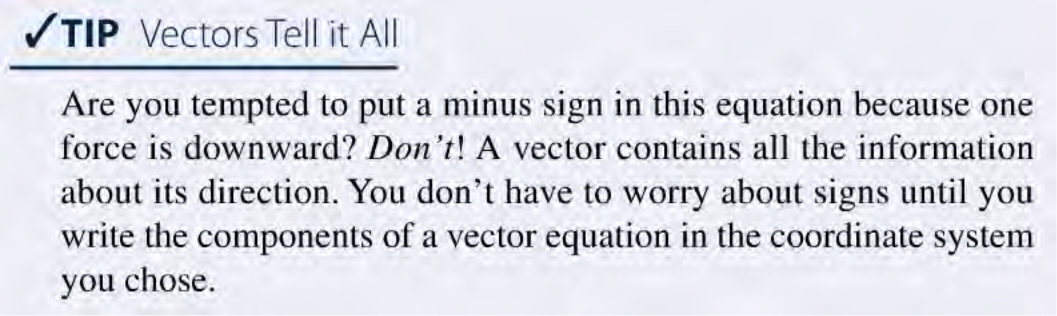


FIGURE 4.12 The forces on the elevator are the cable tension $\vec{T}$ and gravity $\vec{F}_g$.

Wolfson

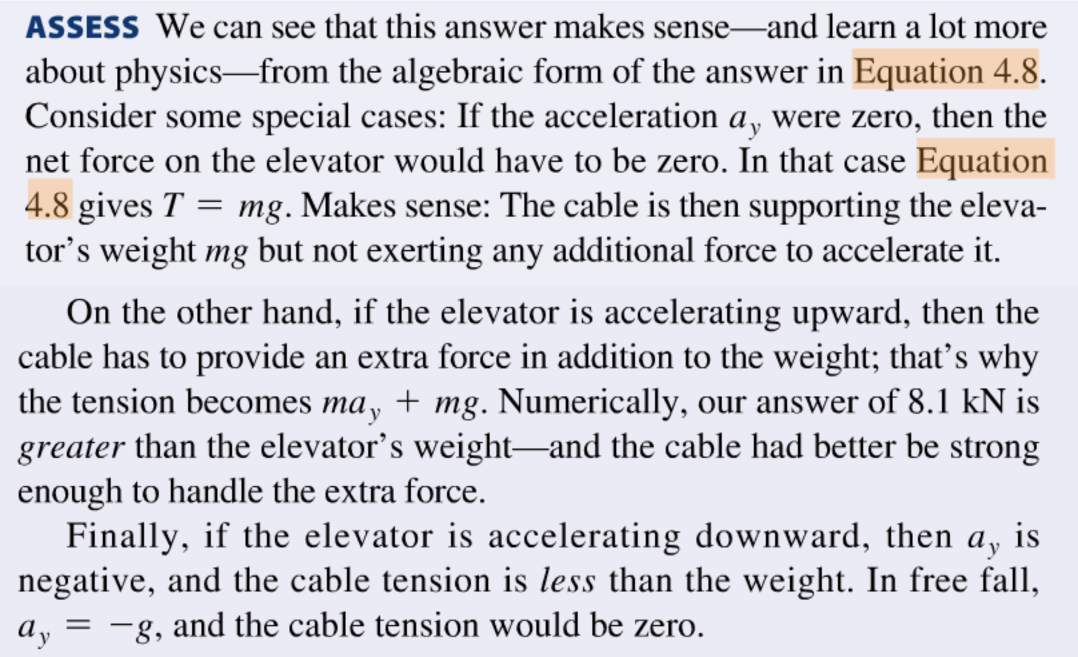
Tips

→ From Wolfson Ex.4.3



✓TIP Vectors Tell it All

Are you tempted to put a minus sign in this equation because one force is downward? *Don't*! A vector contains all the information about its direction. You don't have to worry about signs until you write the components of a vector equation in the coordinate system you chose.



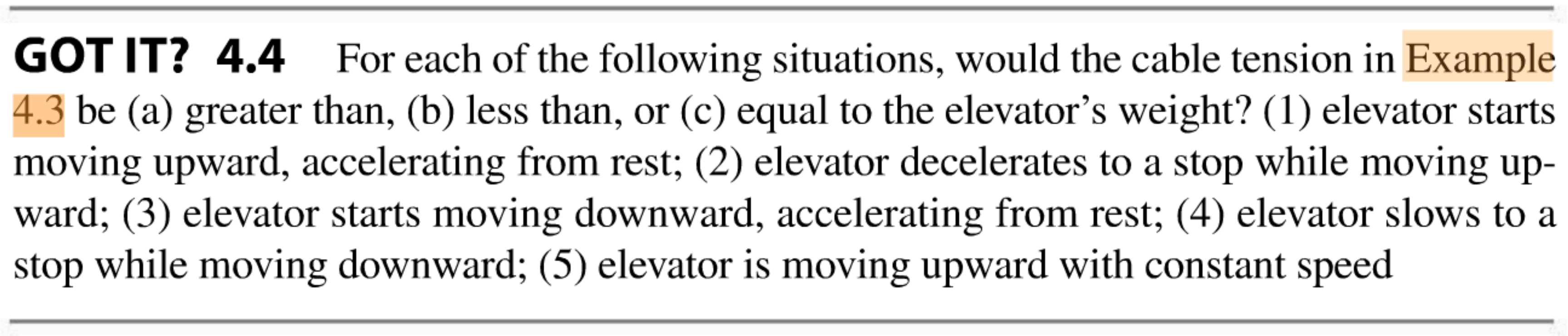
ASSESS We can see that this answer makes sense—and learn a lot more about physics—from the algebraic form of the answer in Equation 4.8. Consider some special cases: If the acceleration a_y were zero, then the net force on the elevator would have to be zero. In that case Equation 4.8 gives $T = mg$. Makes sense: The cable is then supporting the elevator's weight mg but not exerting any additional force to accelerate it.

On the other hand, if the elevator is accelerating upward, then the cable has to provide an extra force in addition to the weight; that's why the tension becomes $ma_y + mg$. Numerically, our answer of 8.1 kN is *greater* than the elevator's weight—and the cable had better be strong enough to handle the extra force.

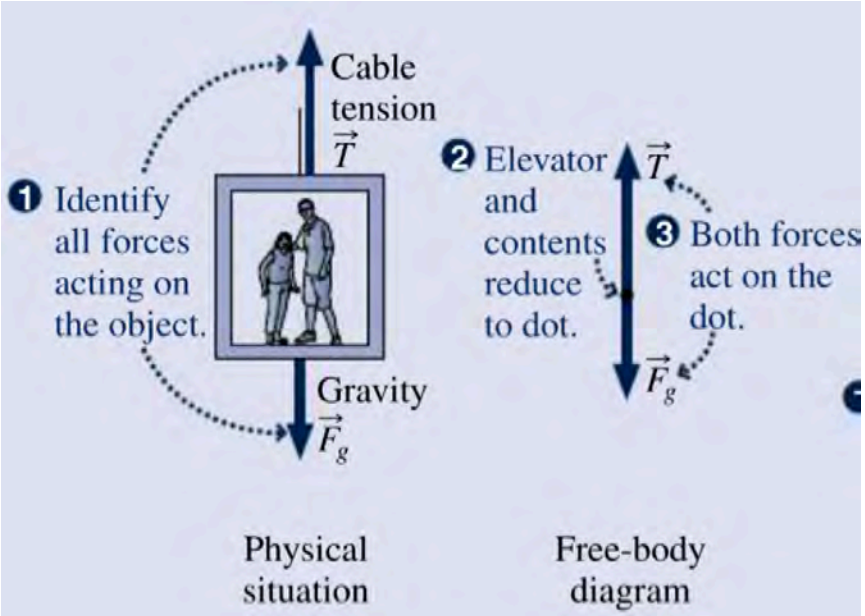
Finally, if the elevator is accelerating downward, then a_y is negative, and the cable tension is *less* than the weight. In free fall, $a_y = -g$, and the cable tension would be zero.

Wolfson

Ex. (SOL)



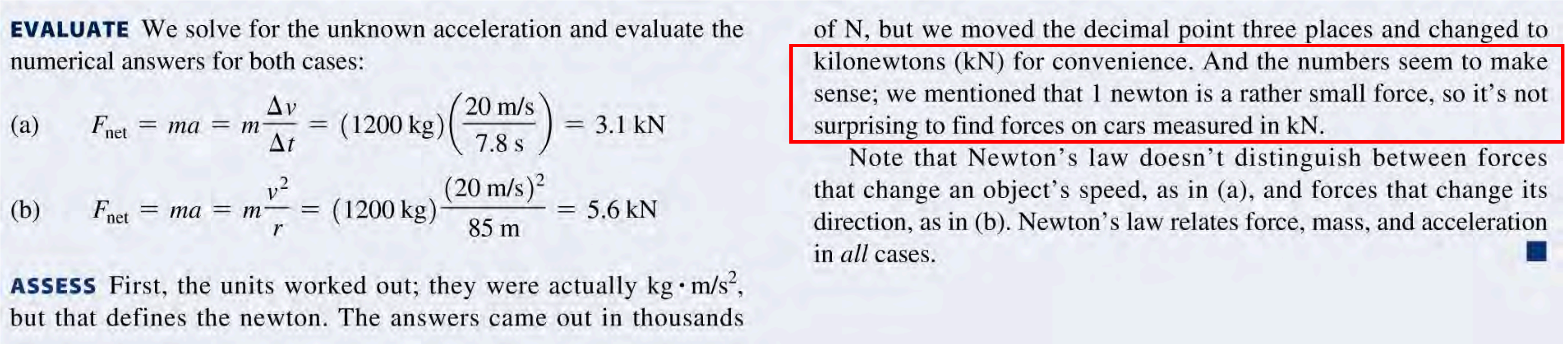
GOT IT? 4.4 For each of the following situations, would the cable tension in Example 4.3 be (a) greater than, (b) less than, or (c) equal to the elevator's weight? (1) elevator starts moving upward, accelerating from rest; (2) elevator decelerates to a stop while moving upward; (3) elevator starts moving downward, accelerating from rest; (4) elevator slows to a stop while moving downward; (5) elevator is moving upward with constant speed



1. a
2. b
3. b
4. a
5. c

→ Try formulating this problem algebraically!

Tips



EVALUATE We solve for the unknown acceleration and evaluate the numerical answers for both cases:

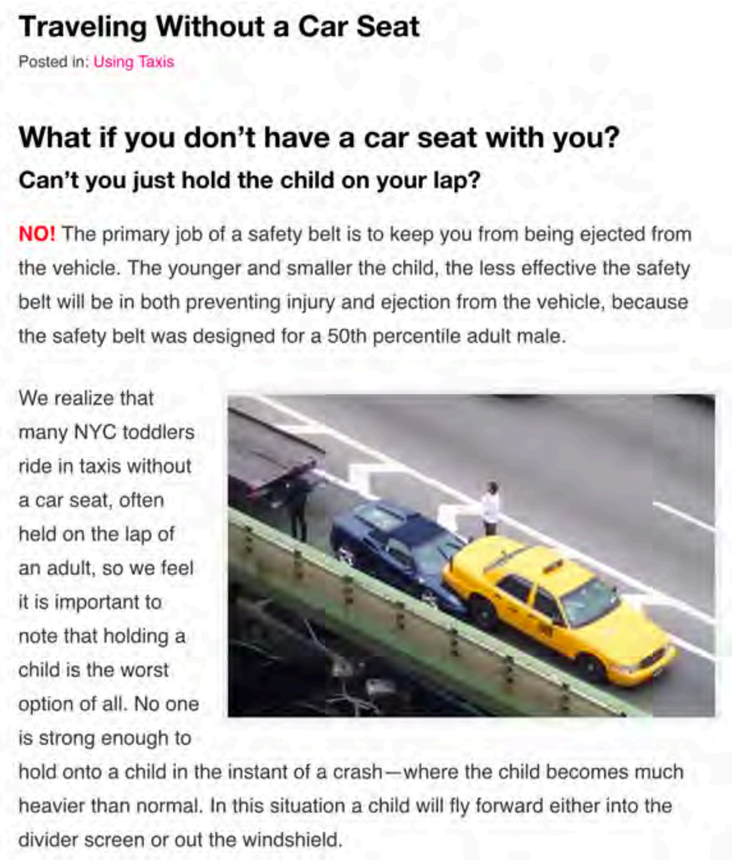
$$\text{(a)} \qquad F_{\text{net}} = ma = m\frac{\Delta v}{\Delta t} = (1200\ \text{kg})\left(\frac{20\ \text{m/s}}{7.8\ \text{s}}\right) = 3.1\ \text{kN}$$

$$\text{(b)} \qquad F_{\text{net}} = ma = m\frac{v^2}{r} = (1200\ \text{kg})\frac{(20\ \text{m/s})^2}{85\ \text{m}} = 5.6\ \text{kN}$$

ASSESS First, the units worked out; they were actually $\text{kg}\cdot\text{m/s}^2$, but that defines the newton. The answers came out in thousands of N, but we moved the decimal point three places and changed to kilonewtons (kN) for convenience. And the numbers seem to make sense; we mentioned that 1 newton is a rather small force, so it's not surprising to find forces on cars measured in kN.

Note that Newton's law doesn't distinguish between forces that change an object's speed, as in (a), and forces that change its direction, as in (b). Newton's law relates force, mass, and acceleration in *all* cases.

→ But not all advice is good (from Wolfson Ex.4.1)



Traveling Without a Car Seat

Posted in: Using Taxis

What if you don't have a car seat with you?

Can't you just hold the child on your lap?

NO! The primary job of a safety belt is to keep you from being ejected from the vehicle. The younger and smaller the child, the less effective the safety belt will be in both preventing injury and ejection from the vehicle, because the safety belt was designed for a 50th percentile adult male.

We realize that many NYC toddlers ride in taxis without a car seat, often held on the lap of an adult, so we feel it is important to note that holding a child is the worst option of all. No one is strong enough to hold onto a child in the instant of a crash—where the child becomes much heavier than normal. In this situation a child will fly forward either into the divider screen or out the windshield.

http://thecarseatlady.com/traveling-without-a-car-seat/

Ex.

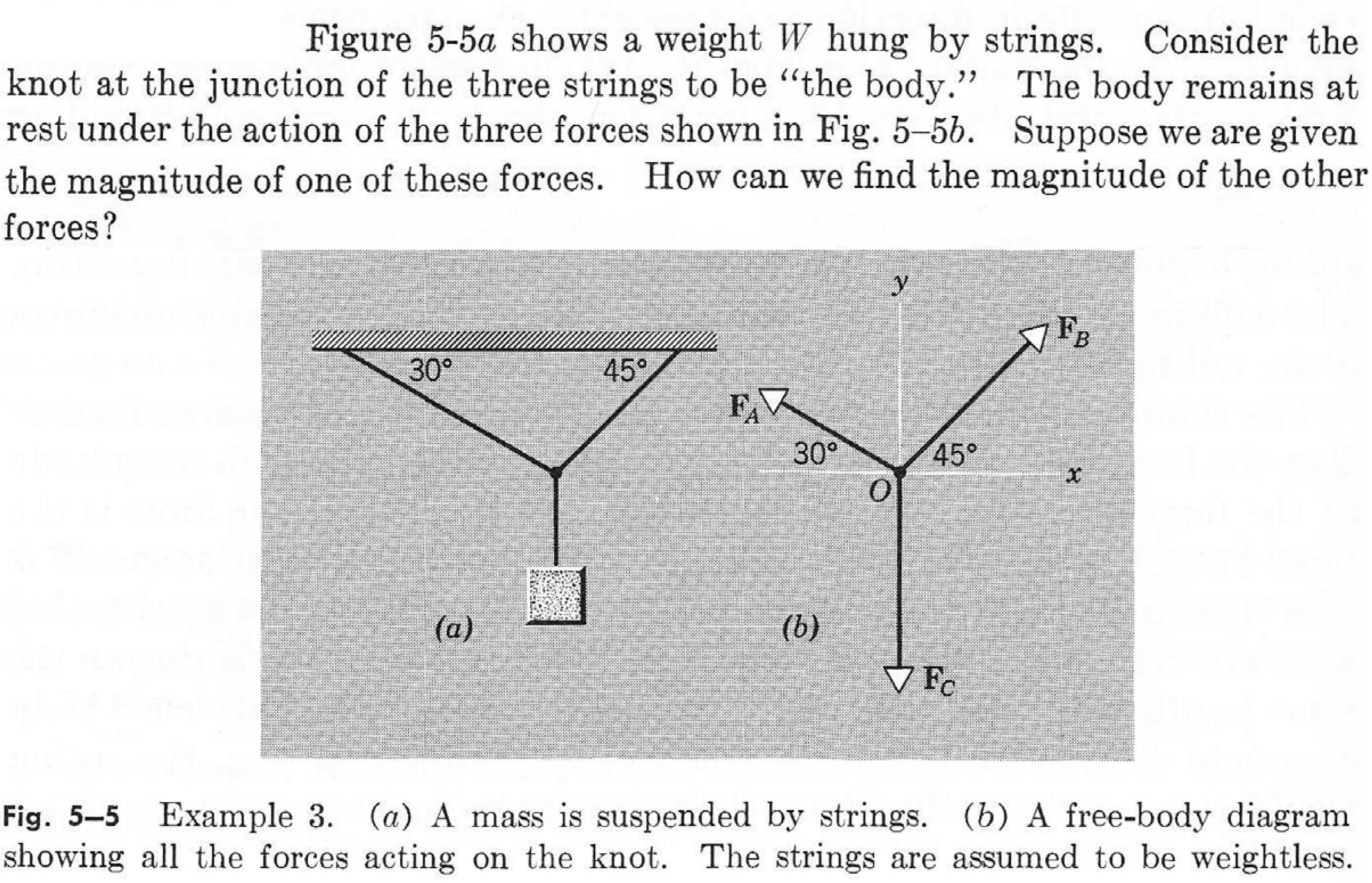


Figure 5-5*a* shows a weight *W* hung by strings. Consider the knot at the junction of the three strings to be "the body." The body remains at rest under the action of the three forces shown in Fig. 5–5*b*. Suppose we are given the magnitude of one of these forces. How can we find the magnitude of the other forces?

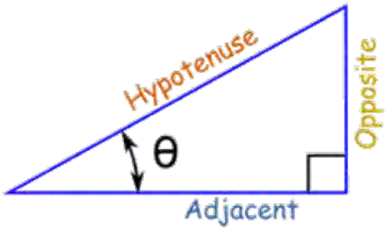
Fig. 5–5 Example 3. (*a*) A mass is suspended by strings. (*b*) A free-body diagram showing all the forces acting on the knot. The strings are assumed to be weightless.

- Draw a free-body diagram
- Turn this into a pair of 1-D problems
- Set up the trigonometric relationships correctly

$$\sin\theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$\cos\theta = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

$$\tan\theta = \frac{\text{Opposite}}{\text{Adjacent}}$$



Resnick & Halliday (1966)

Ex. (SOL)

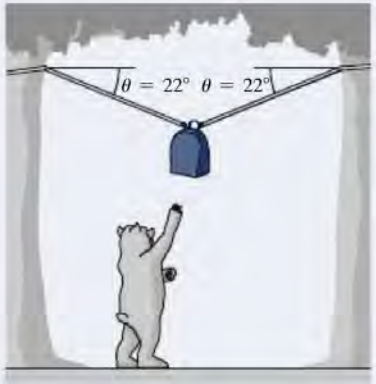
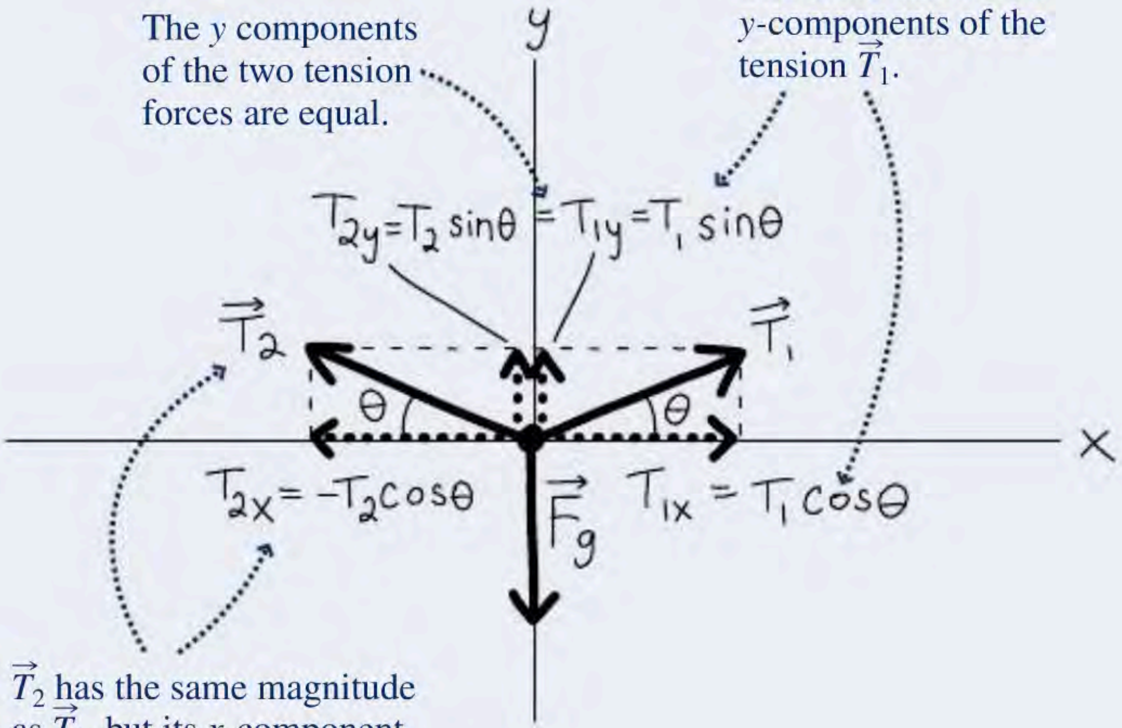


FIGURE 5.3 Bear precautions.



The y components of the two tension forces are equal.

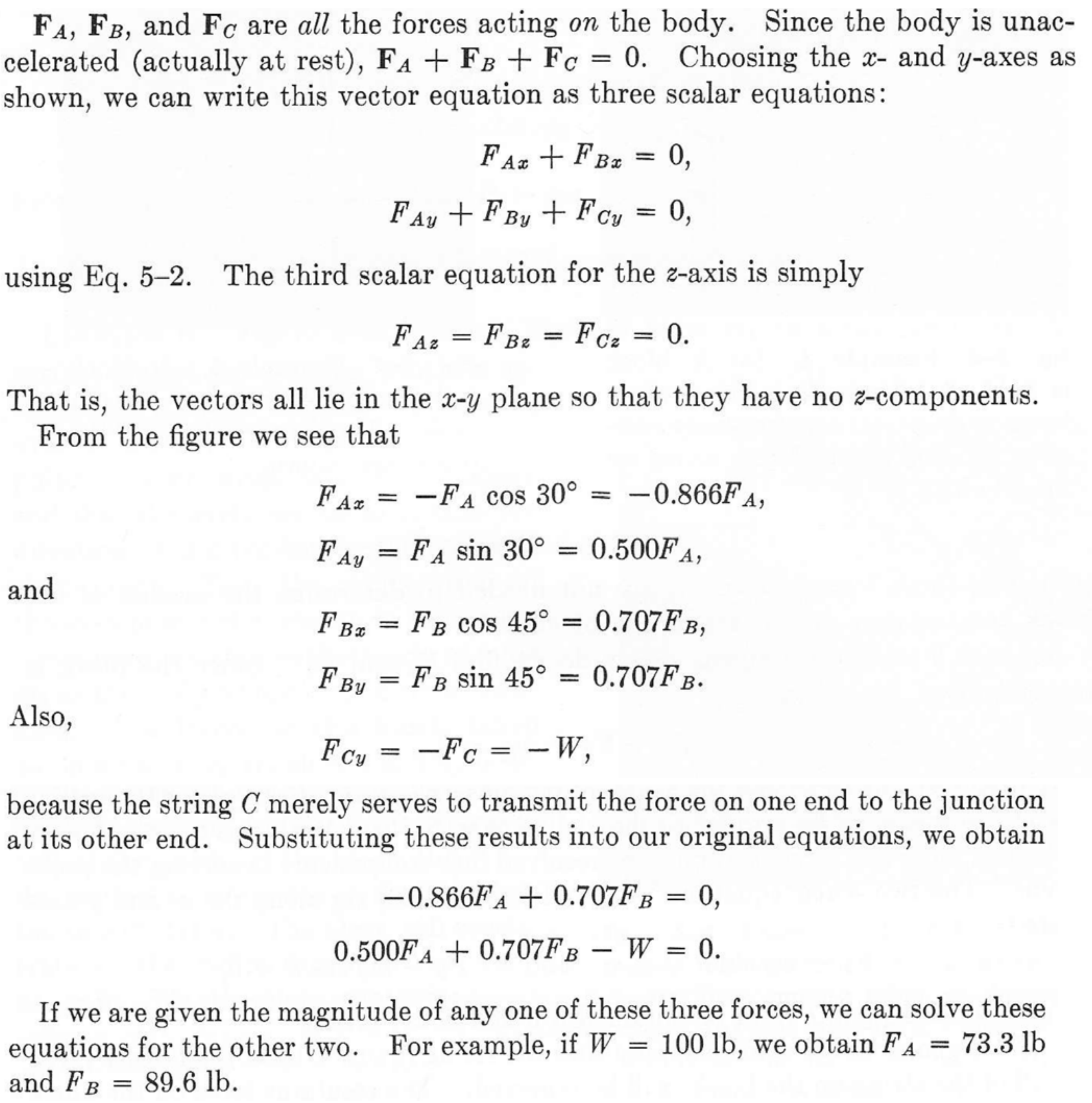
These are the x- and y-components of the tension $\vec{T}_1$.

$\vec{T}_2$ has the same magnitude as $\vec{T}_1$, but its x-component is opposite.

FIGURE 5.4 Our free-body diagram for the pack.

Wolfson

Ex. (SOL)



$\mathbf{F}_A$, $\mathbf{F}_B$, and $\mathbf{F}_C$ are *all* the forces acting *on* the body. Since the body is unaccelerated (actually at rest), $\mathbf{F}_A + \mathbf{F}_B + \mathbf{F}_C = 0$. Choosing the x- and y-axes as shown, we can write this vector equation as three scalar equations:

$$F_{Ax} + F_{Bx} = 0,$$

$$F_{Ay} + F_{By} + F_{Cy} = 0,$$

using Eq. 5–2. The third scalar equation for the z-axis is simply

$$F_{Az} = F_{Bz} = F_{Cz} = 0.$$

That is, the vectors all lie in the x-y plane so that they have no z-components.

From the figure we see that

$$F_{Ax} = -F_A \cos 30^\circ = -0.866F_A,$$

$$F_{Ay} = F_A \sin 30^\circ = 0.500F_A,$$

and

$$F_{Bx} = F_B \cos 45^\circ = 0.707F_B,$$

$$F_{By} = F_B \sin 45^\circ = 0.707F_B.$$

Also,

$$F_{Cy} = -F_C = -W,$$

because the string C merely serves to transmit the force on one end to the junction at its other end. Substituting these results into our original equations, we obtain

$$-0.866F_A + 0.707F_B = 0,$$

$$0.500F_A + 0.707F_B - W = 0.$$

If we are given the magnitude of any one of these three forces, we can solve these equations for the other two. For example, if $W = 100$ lb, we obtain $F_A = 73.3$ lb and $F_B = 89.6$ lb.

Note: In it's generality, the solution allowed for a z-component (though it isn't really needed and this can be treated as a 2-D problem)

Note: Algebraically, in the end you end up w/ two eqns. and two unknowns

Resnick & Halliday (1966)

Frame of reference

- For someone on the ground watching the cat, they are falling....

  - .... (and ignoring that the cat knows it's falling) the cat just thinks someone turned off gravity

→ This dichotomy motivates the idea that different things can happen depending upon different frames of reference

Related Tangent: If astronauts are in "free fall", how come they don't fall into the earth?

→ Because it is in "orbit" (i.e., the tangential velocity allows the object to keep along a curved trajectory; this ties back to uniform circular motion)

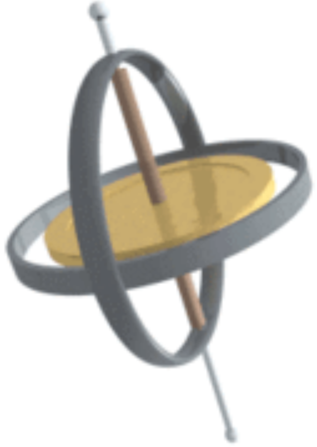
https://www.wired.com/2011/07/why-do-astronauts-float-around-in-space/

Aside: Rotating frames

As the tire goes round, is it easy to describe the location of that part of the tire in Cartesian coords? Is there a better way to do it?

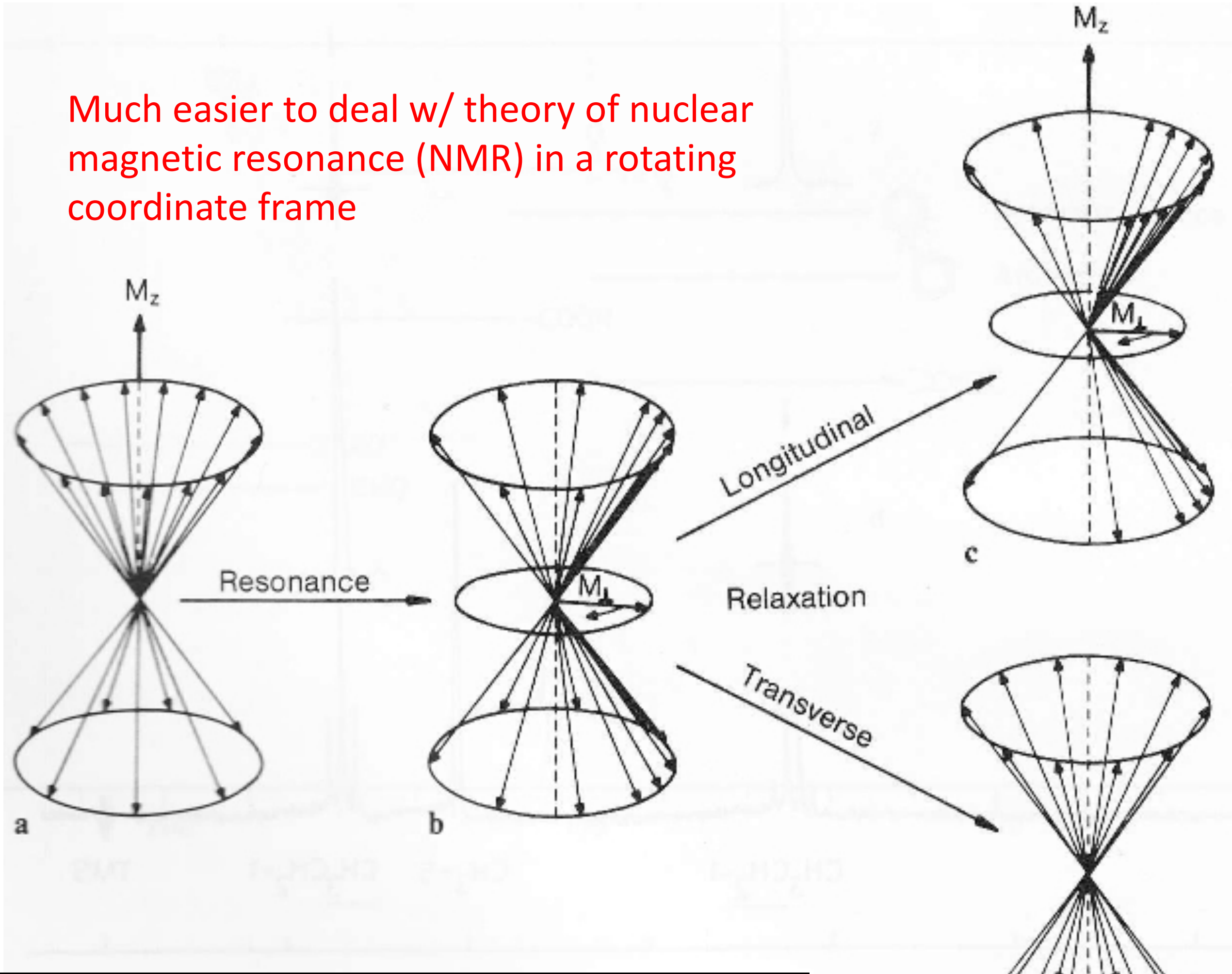
Consider watching what is going on on a carousel when standing off it versus riding it

Aside: Rotating frames



https://en.wikipedia.org/wiki/Precession

Much easier to deal w/ theory of nuclear magnetic resonance (NMR) in a rotating coordinate frame



Hoppe

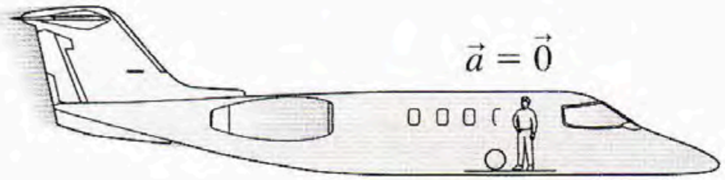
Wikipedia

→ NMR is the basis for magnetic resonance imaging (MRI)

Inertial Reference Frames

- Similar to walking along on a (moving) train
- Frame of reference is inertial if it is in uniform motion (which also includes being at rest). That is, the frame itself is not accelerating
- Strictly speaking, “Earth” is not an inertial frame (due to the rotation of earth)

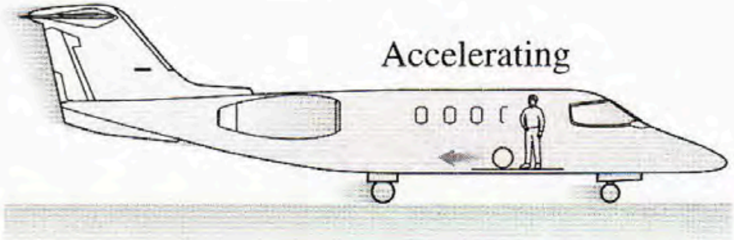
(a)



The ball stays in place.

A ball with no horizontal forces stays at rest in an airplane cruising at constant velocity. The airplane is an inertial reference frame.

(b)



The ball rolls to the back.

The ball rolls to the back of the plane during takeoff. An accelerating plane is not an inertial reference frame.

Knight (2013)

→ Newton’s laws only apply in inertial reference frames

<u>Ex.</u> – “Birds on a lorry”

“It is a head-scratching riddle which has troubled scientists and amateurs alike for generations: Would a lorry carrying birds weigh less if they were all flying?”

Lorry (= truck)

http://www.telegraph.co.uk/news/uknews/11345183/Birds-in-a-lorry-riddle-finally-solved-by-Stanford-University.html

Ex.– “Birds on a lorry” (SOL)

→ In short, to first order, no.

https://www.youtube.com/watch?v=lVeP6oqH-Qo

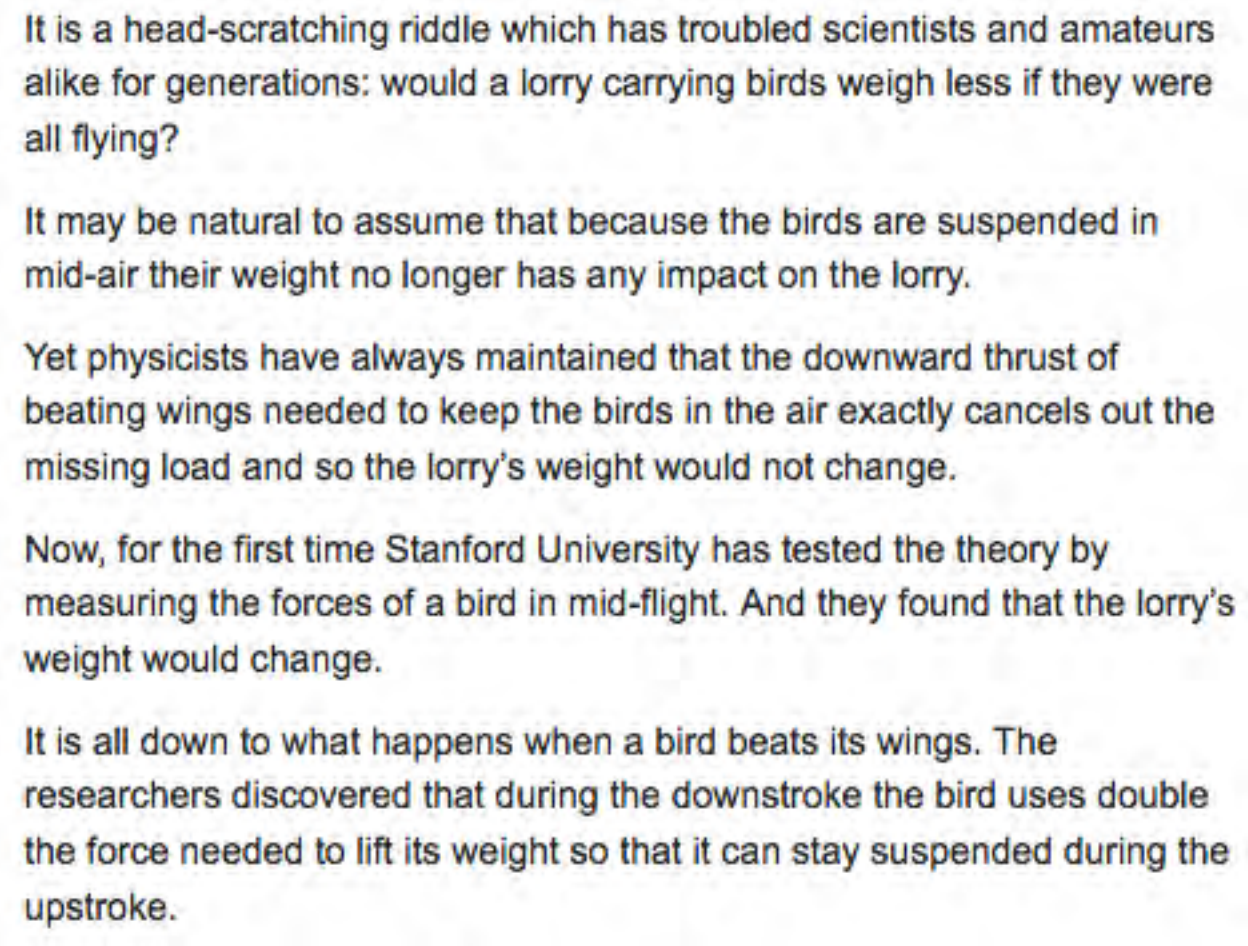
Birds in a Truck - Mythbusters for the Impatient

Mythbusters for the Impatient

44,035 views

Ex.– “Birds on a lorry” (SOL)

→ However, upon careful analysis....



It is a head-scratching riddle which has troubled scientists and amateurs alike for generations: would a lorry carrying birds weigh less if they were all flying?

It may be natural to assume that because the birds are suspended in mid-air their weight no longer has any impact on the lorry.

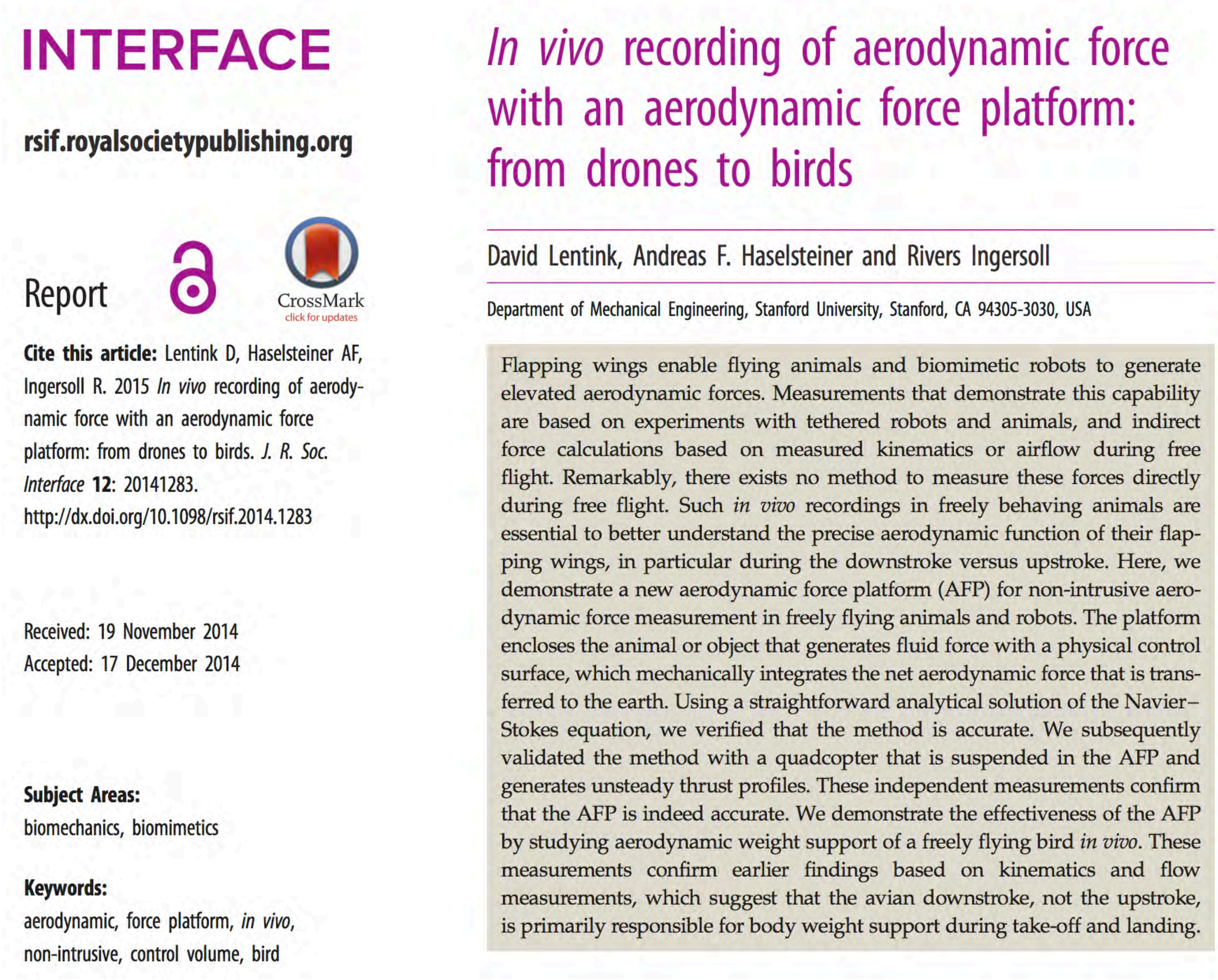
Yet physicists have always maintained that the downward thrust of beating wings needed to keep the birds in the air exactly cancels out the missing load and so the lorry’s weight would not change.

Now, for the first time Stanford University has tested the theory by measuring the forces of a bird in mid-flight. And they found that the lorry’s weight would change.

It is all down to what happens when a bird beats its wings. The researchers discovered that during the downstroke the bird uses double the force needed to lift its weight so that it can stay suspended during the upstroke.

http://www.telegraph.co.uk/news/uknews/11345183/Birds-in-a-lorry-riddle-finally-solved-by-Stanford-University.html

Ex.– “Birds on a lorry” (SOL)



INTERFACE

rsif.royalsocietypublishing.org

Report

CrossMark
click for updates

Cite this article: Lentink D, Haselsteiner AF, Ingersoll R. 2015 *In vivo* recording of aerodynamic force with an aerodynamic force platform: from drones to birds. *J. R. Soc. Interface* **12**: 20141283.
http://dx.doi.org/10.1098/rsif.2014.1283

Received: 19 November 2014
Accepted: 17 December 2014

Subject Areas:
biomechanics, biomimetics

Keywords:
aerodynamic, force platform, *in vivo*, non-intrusive, control volume, bird

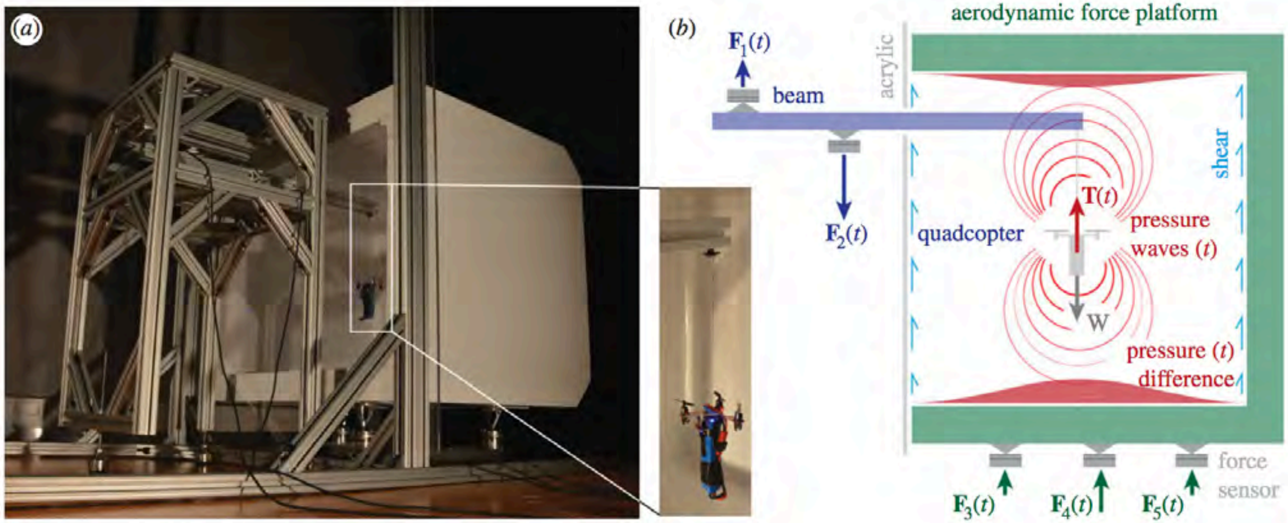
In vivo recording of aerodynamic force with an aerodynamic force platform: from drones to birds

David Lentink, Andreas F. Haselsteiner and Rivers Ingersoll

Department of Mechanical Engineering, Stanford University, Stanford, CA 94305-3030, USA

Flapping wings enable flying animals and biomimetic robots to generate elevated aerodynamic forces. Measurements that demonstrate this capability are based on experiments with tethered robots and animals, and indirect force calculations based on measured kinematics or airflow during free flight. Remarkably, there exists no method to measure these forces directly during free flight. Such *in vivo* recordings in freely behaving animals are essential to better understand the precise aerodynamic function of their flapping wings, in particular during the downstroke versus upstroke. Here, we demonstrate a new aerodynamic force platform (AFP) for non-intrusive aerodynamic force measurement in freely flying animals and robots. The platform encloses the animal or object that generates fluid force with a physical control surface, which mechanically integrates the net aerodynamic force that is transferred to the earth. Using a straightforward analytical solution of the Navier–Stokes equation, we verified that the method is accurate. We subsequently validated the method with a quadcopter that is suspended in the AFP and generates unsteady thrust profiles. These independent measurements confirm that the AFP is indeed accurate. We demonstrate the effectiveness of the AFP by studying aerodynamic weight support of a freely flying bird *in vivo*. These measurements confirm earlier findings based on kinematics and flow measurements, which suggest that the avian downstroke, not the upstroke, is primarily responsible for body weight support during take-off and landing.

Ex.– “Birds on a lorry” (SOL)



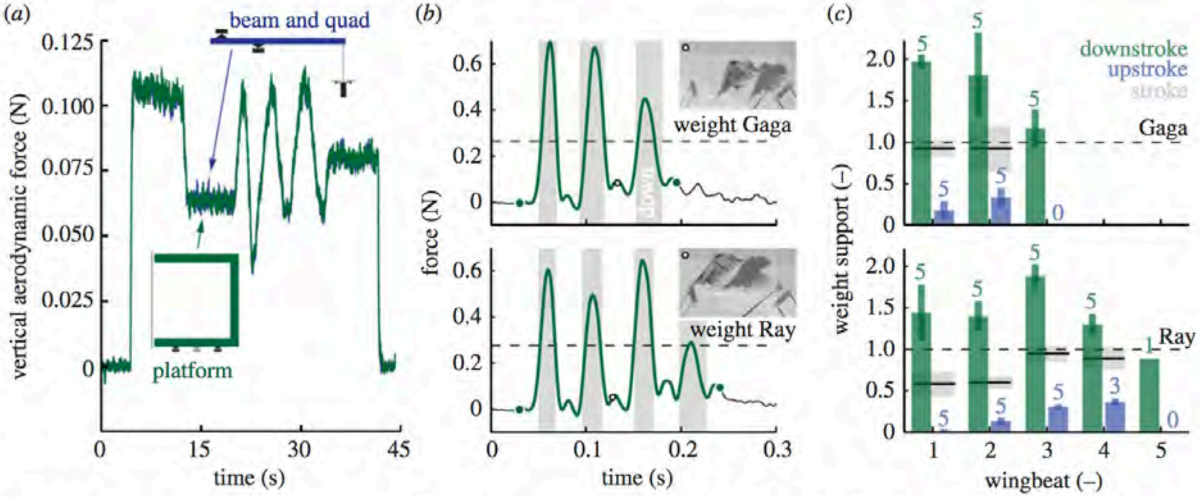


Figure 2. The aerodynamic force platform measures weight support of a quadcopter and freely flying birds *in vivo*. (*a*) The quadcopter's unsteady thrust measured with the platform (green) versus beam (blue) overlap, confirming that the platform is accurate (fourth-order Butterworth filter with 30 Hz cut-off for AFP and beam). (*b*) Force-platform measurements of two Pacific parrotlets (Gaga and Ray) flying between two perches at 0.28 m distance in the AFP (fourth-order Butterworth filter with 60 Hz cut-off; green circle, take-off and landing; circle with black outline, video frame; grey area, downstroke). The snapshots illustrate that the feathers open the wing surface like a venetian blind during the upstroke. (*c*) Calculation of wingbeat-averaged weight support based on raw data (flights, $n = 5$; birds, $N = 2$). During take-off, Ray pushes off more vertically than Gaga, as illustrated in the electronic supplementary material videos. The start of the downstroke and upstroke is defined as the moment when the wing is at its highest and lowest position, for the last wingstroke(s) we evaluate stroke direction. (Online version in colour.)