Physics of Sports

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http://pages.jh.edu/~maliyou1/Physics_of_Sports/

Image https://www.disneyclips.com/imagesnewb/skating.html

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Course Goals

- This is a short course which starts with the assumption that you know at least some basic mechanics. It follows the “standard” physics approach in a hidden way
- By the end of the course, you will:

1. Develop a deeper understanding of basic physics concepts via their applications to sports.
2. Learn image, video and sound analysis (using software) to help you extract useful data from sporting events.
3. Develop an appreciation for the amount of science and engineering that goes into a sporting event, from the training of players to the design of equipment and playing fields.

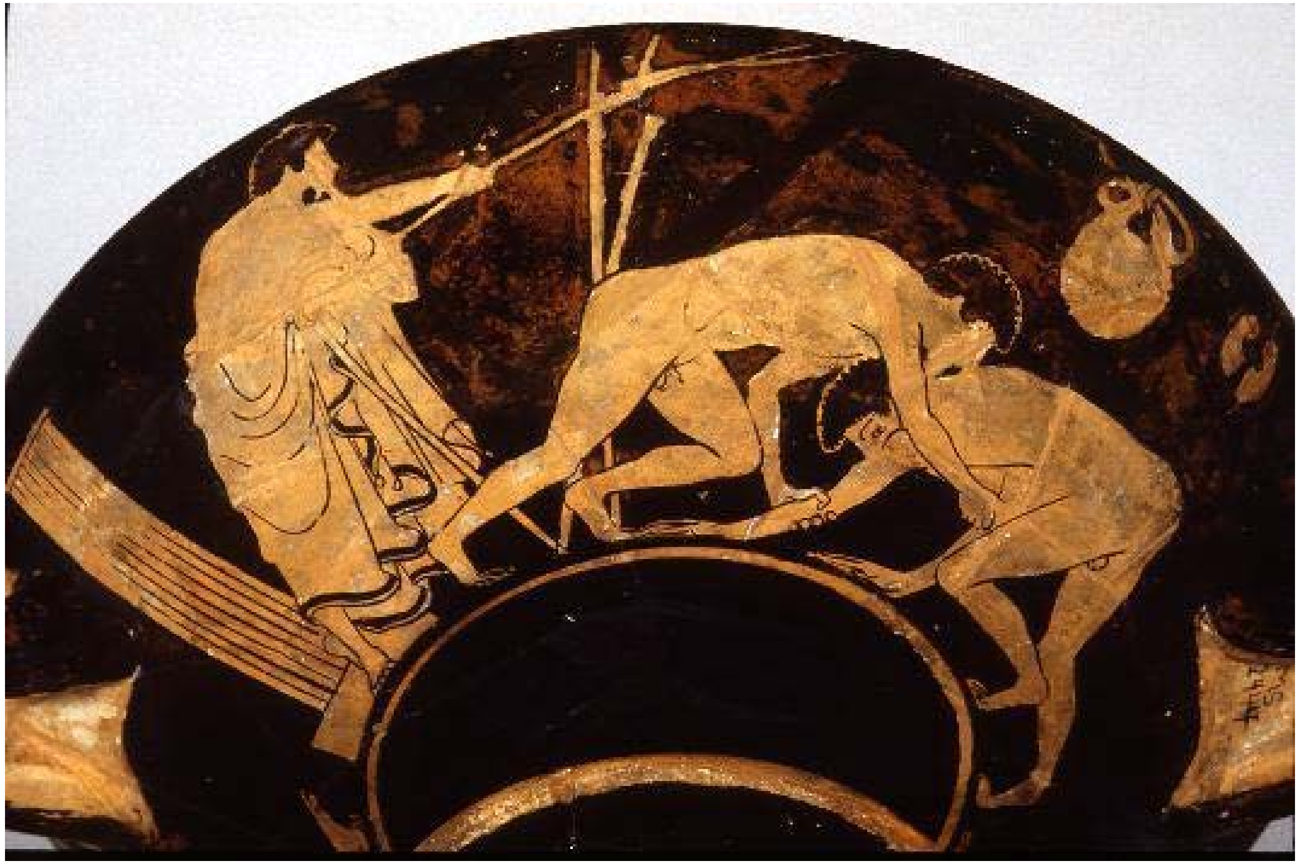
General Comments

1. Missed class of 1/8 and MLK day class
2. When should we meet in lieu of Monday 15th?
3. The course follows a “standard” physics approach in a hidden way
4. Grading is based on your participation
5. Projects count as 40% (+ 30% two written assignments and 30% class participation.)
6. **Today, you have to come up with some idea of what type of project you would like to do in the remaining two weeks.**

Projects

- What would be counted as a project?
- Essentially, a deeper self-study of the physics of a particular sport.
- This may include reading some websites/papers, analyzing photos/videos or, time permitting, collecting your own data and analyzing it.

Day 2 - Role of Various Forces in Sports



Trainer watching wrestlers

Photograph by Maria Daniels, courtesy of The University of Pennsylvania Museum of Archaeology and Anthropology

http://www.perseus.tufts.edu/Olympics/sports.html

Plan for Today

- How Things Interact: Forces
- The Physics of a Dwight Howard Dunk
- Sideways Traction
- More-Complex Situations (?)
- “Imaginary Forces” in Sports

Based on Chapter 3, Mike Lisa “The Physics of Sports”

But before we move forward, let's finish the discussion we had started in an email earlier about skating shoes and skis:

https://www.britannica.com/sports/ski-jumping

https://www.youtube.com/watch?v=msdnxqpE0iA

Write your name here:_______________________________

If you are hired by a company to design better ‘shoes’ for each sport, which three variables will you focus on?

1.________________
2.________________
3.________________

1.________________
2.________________
3.________________

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How Things Interact: Forces

MENS FREESTYLE 66KG BRONZE CONTEST
ATHENS - AUGUST 28: Makhach Martazaliev of Russia competes against Leonid Spiridonov (red) of Kazakhstan during the men's Freestyle wrestling 66 kg bronze medal match on August 28, 2004 during the Athens 2004 Summer Olympic Games at Ano Liossia Olympic Hall in Athens, Greece. (Photo by Stuart Franklin/Getty Images)

https://www.olympic.org/wrestling-freestyle/60-66kg-men

How Things Interact: Forces

- All of sports hinges on the cause of acceleration – objects (or people) accelerate due to their interactions with other objects (or people).
    - A golf ball accelerates due to its interaction with a club;
    - a baseball player accelerates as he slides into third base due to his interaction with the ground;
    - a tennis ball accelerates (slows down) as it interacts with the air it passes through;
    - a diver accelerates downward as she interacts gravitationally with the Earth.
- In a scientific approach to sports, we quantify all of these interactions in terms of forces.

Lisa, Michael. *The Physics of Sports*. McGraw-Hill Higher Education, 2015.

How Things Interact: Forces

- A force is basically a push or a pull that one object exerts on another.
- Forces are vectors, which means they have

(1) a magnitude, quantifying the strength of the push or pull;

(2) a direction, because one can be pushed left, right, up, or down; and

(3) a unit of measure.

- The unit of force is pound (lb) in the Imperial system and Newton (N) in the SI system.

Lisa, Michael. *The Physics of Sports*. McGraw-Hill Higher Education, 2015.

Thinking about forces in sports, which ones come to your mind?

- Weight
- Friction
- ____________________
- ____________________
- ____________________

The type of forces we'll discuss in this course:

From page 41 of Lisa, Michael. The Physics of Sports. McGraw-Hill Higher Education, 2015

How Things Interact: Forces

Q. When a hockey player takes a shot from deep in his own zone towards the other end of the rink 200 feet away, one hardly notices the puck slowing down at all. The coefficient of kinetic friction between a puck and the ice is about 0.03.

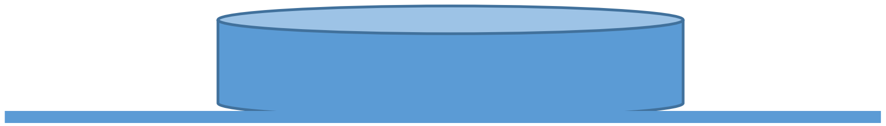
a) If a player shoots at 80 mph, how fast is the puck moving 200 feet later? Give your answer in mph, and use at least four significant digits.

b) What if there were no rink at all, just a large lake of ice? If the player took the same shot, how far would the puck go, before it came to rest? Express your answer in miles.

Problem 1, Page 76 of Lisa, Michael. The Physics of Sports. McGraw-Hill Higher Education, 2015

Solution (hint):

- Draw a free body diagram of the puck and label all forces
- Use Newton's law to find the acceleration
- (Part a) Use kinematic equations to find the final velocity
- (Part b) Use kinematic equations to find the distance



$$x = v_{0x}t + \frac{1}{2}a_x t^2$$

$$x = \frac{v_{0x} + v_{fx}}{2}t$$

$$v_{fx} = v_{0x} + a_x t$$

$$2a_x x = v_{fx}^2 - v_{0x}^2$$

Open ended question?

- Hit an object of known mass and find the coefficient of friction

How Things Interact: Forces

- Fact: In order to stay frozen, the surface of the ice rink must stay near 24 F at all times.

How Things Interact: Forces

Q. The coefficient of kinetic friction between a curling stone and ice is 0.05. The stone is typically launched with a velocity of 2 m/s. It reaches this speed after a player pushes the stone from the hashline to the hogline, a total of 33 ft.

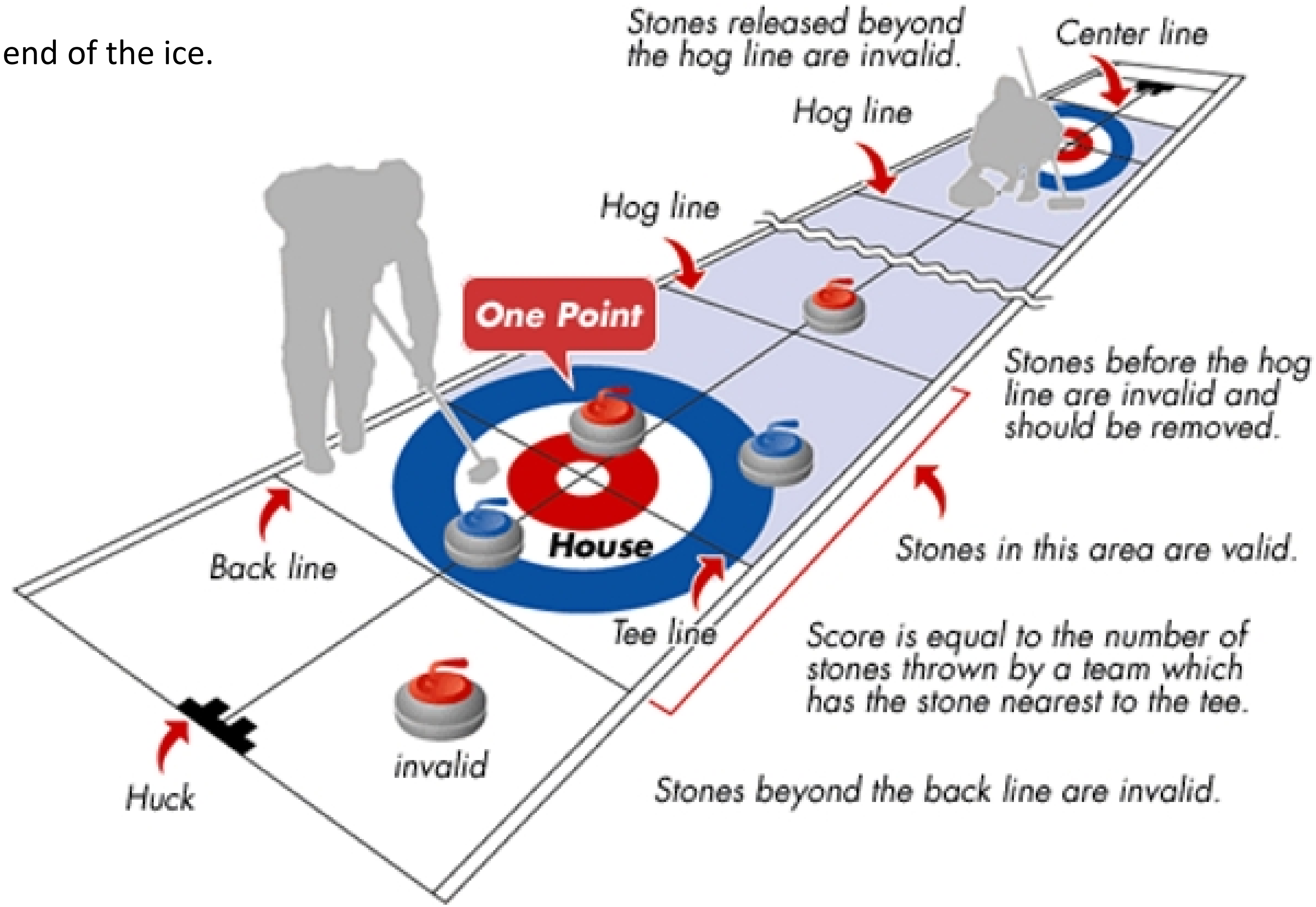
(a) Assuming constant acceleration over this push, what is the force the player puts on the stone? Express your answer in pounds.

(b) If the player exerts twice the force on the stone, will he generate twice the acceleration? Why or why not?

Problem 7, Page 77 of Lisa, Michael. The Physics of Sports. McGraw-Hill Higher Education, 2015

HOG LINE
A line 10 meters from the hack at each end of the ice.

The rules are simple – to slide a stone (about 20kg) down the "rink" (about 40m) to a target (house) on the ice. The Player slides from the "hack" and releases the stone on (hopefully) the right path. As the stone is released the handle is twisted left or right to make it "curl" hence CURLING!!!



https://www.gla.ac.uk/myglasgow/staff/staffclubsandorganisations/curling/

http://www.richmondcurling.com/rentals/curling__trashed/12-minute-curling/

How Things Interact: Forces

- Open-ended question: If you were to design shoes for this sport, what will be your choice for:
- 1. Curler shoes?
- 2. Slider shoes?

Watch “SCIENCE FRICTION: All About the Physics of Curling”,

https://youtu.be/miB7HzUvmM0?t=1m22s

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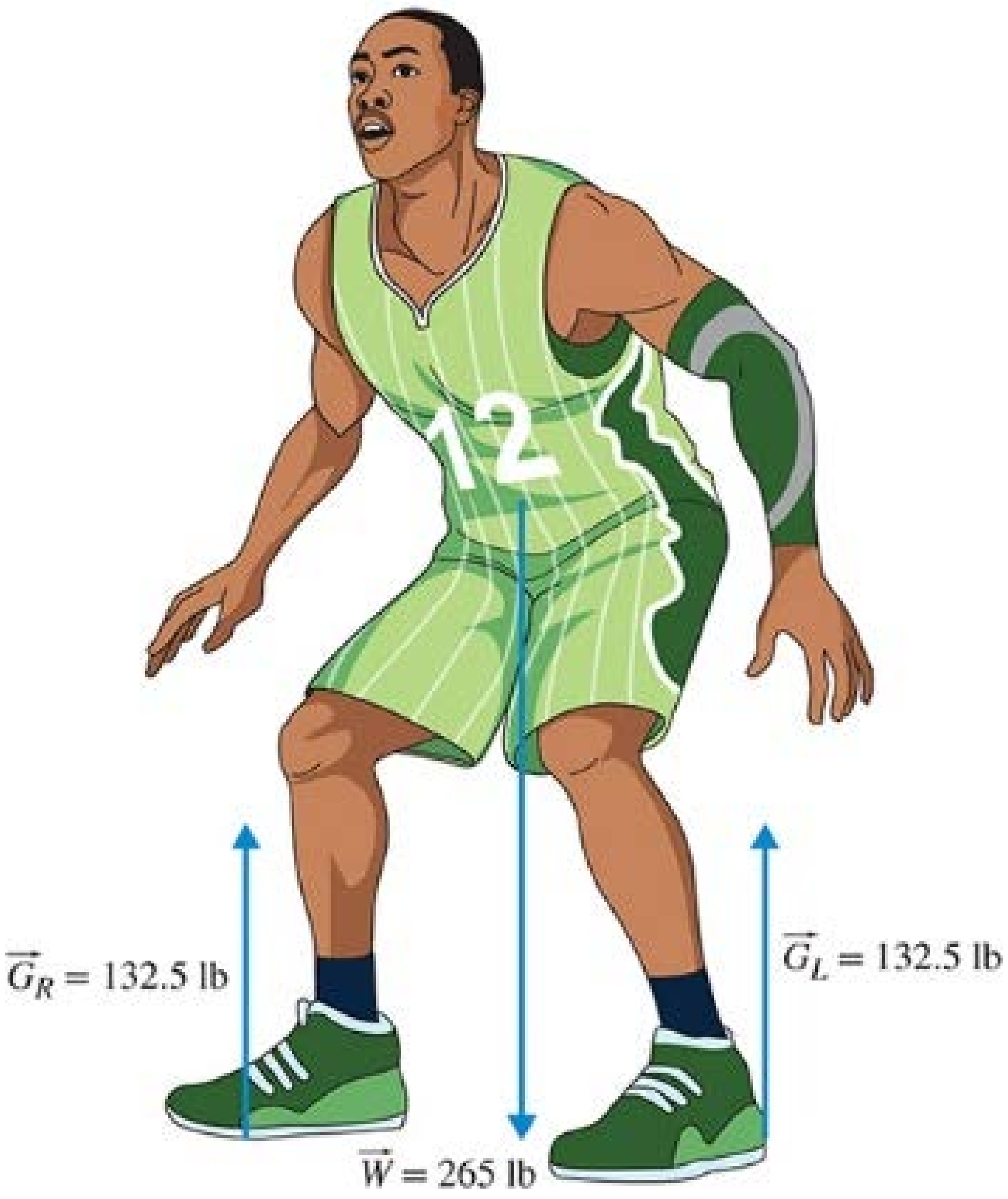
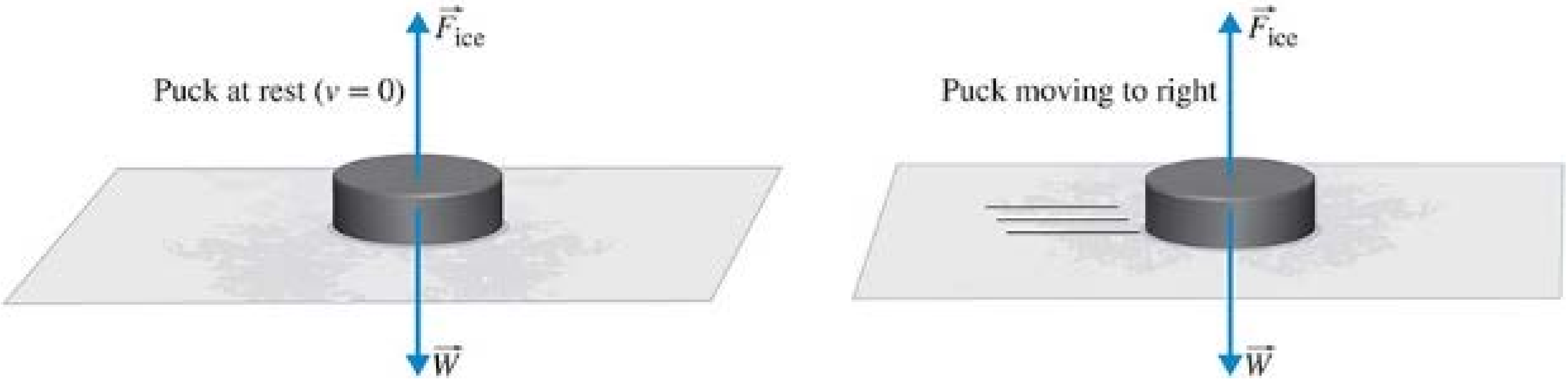
Based on Chapter 3, Mike Lisa “The Physics of Sports”

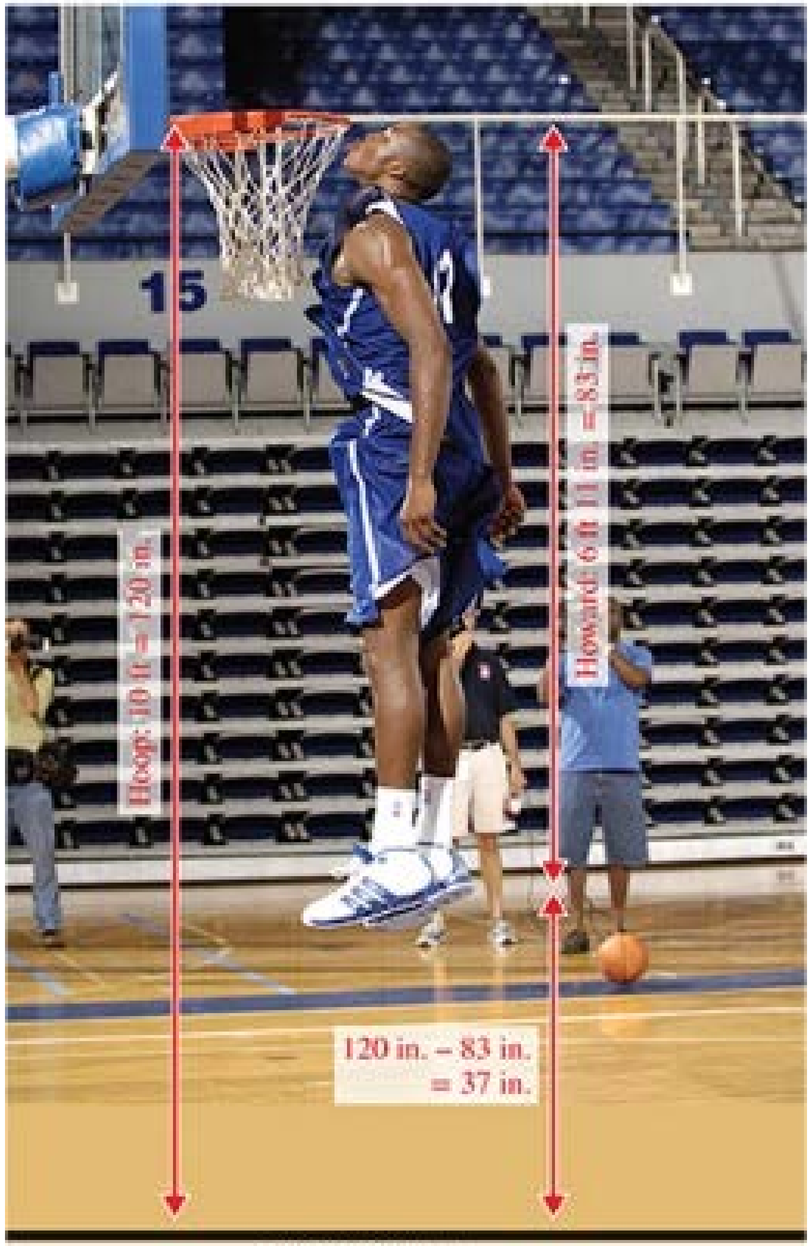
Howard waiting for the pass. This is a free-body diagram (FBD) showing all forces acting on Howard: the downward force of gravity and the upward forces from the floor on his feet. At this moment, the forces cancel each other out, so Howard is not accelerating - he is in equilibrium.





A puck at rest is in equilibrium, as is one moving to the right at constant speed. Is it also in equilibrium?

Dwight Howard kisses the rim during training camp in 2005. Knowing his height and the height of a rim, we can accurately estimate his vertical jump. In the photo, he is 37 in. above the ground and his lips are about 2 in. from the hoop. In this or other attempts, Howard's lips reportedly do touch the rim, so his vertical is certainly at least 39 in. Claims of a 40-in. vertical seem quite believable.



© NBAE/Getty Images

The Physics of a Dwight Howard Dunk (cont.)

Q. A 42-in. vertical jump consists of two parts. The first stage is the quick acceleration of the center of mass from a crouching to a standing position. The center of mass rises by 20 cm in this stage. In the second stage, the player's feet leave the floor and the center of mass rises 42 in. under the influence of gravity alone.

(a) What is the player's velocity just as his feet leave the floor?

(b) What is the average acceleration during the first phase of the jump?

(c) What is the average acceleration during the second phase of the jump?

(d) If the player is 185 lb, what force do his legs need to exert, to execute this jump?

Problem 12, Page 77 of Lisa, Michael. *The Physics of Sports*. McGraw-Hill Higher Education, 2015

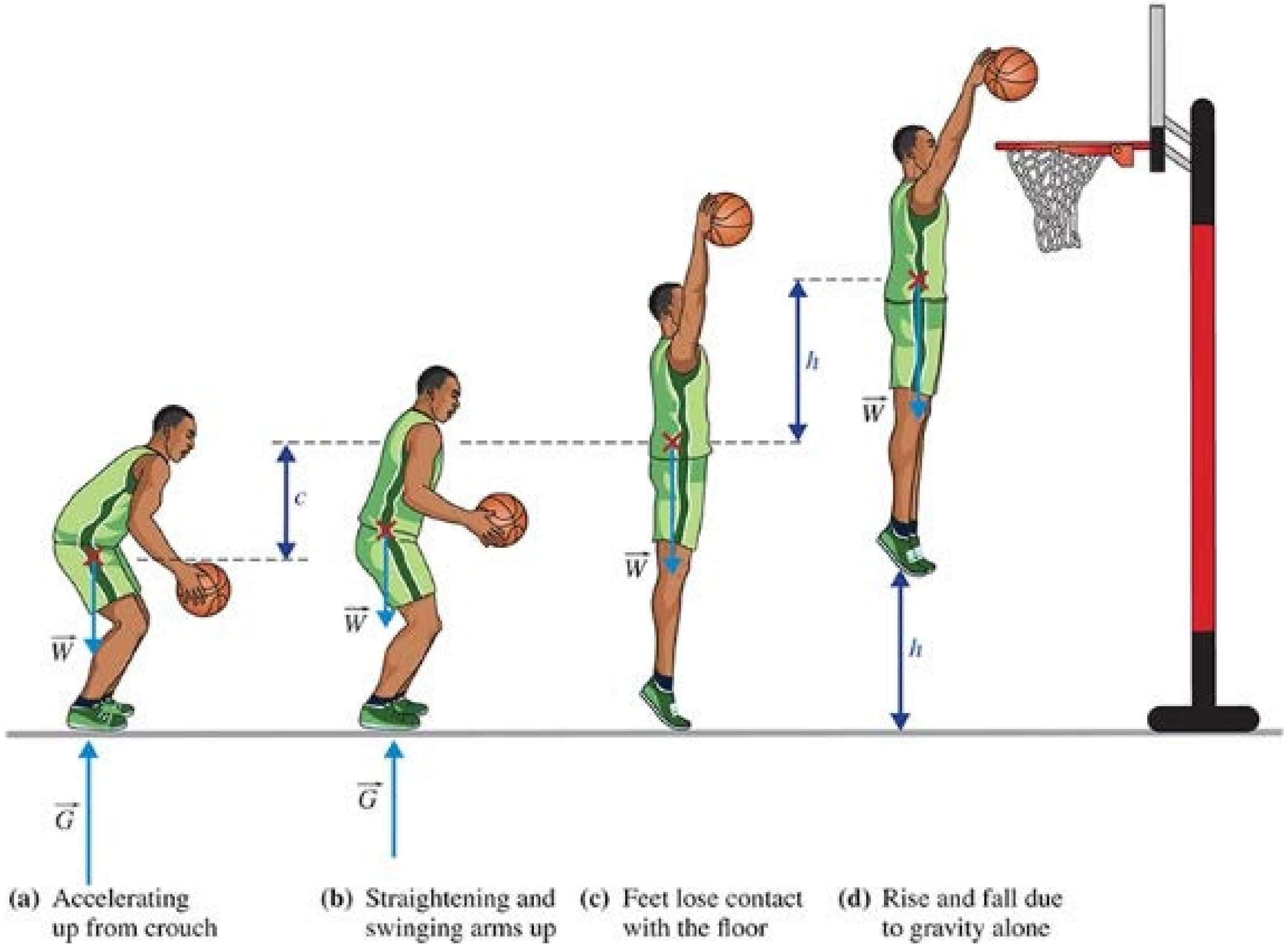
Solution:

$$x = v_{0x}t + \frac{1}{2}a_x t^2$$

$$x = \frac{v_{0x} + v_{fx}}{2}t$$

$$v_{fx} = v_{0x} + a_x t$$

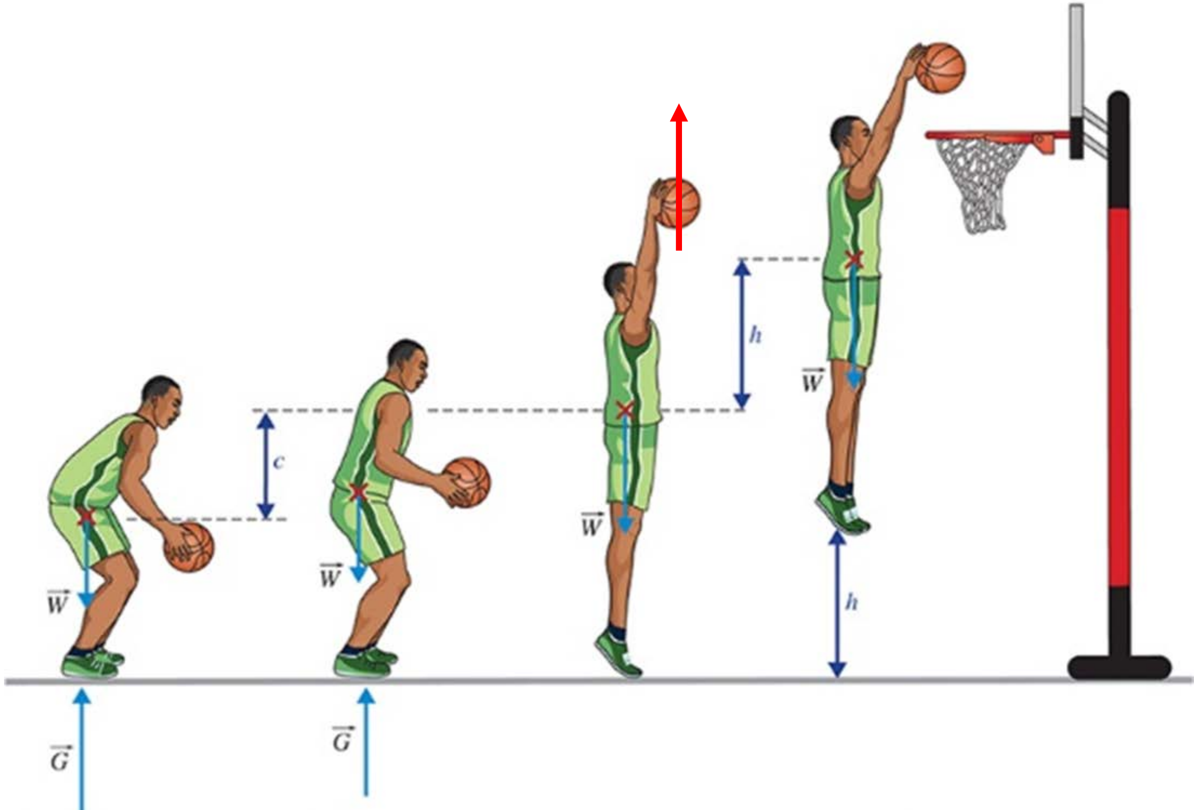
$$2a_x x = v_{fx}^2 - v_{0x}^2$$



The mechanics of Dwight Howard's vertical leap. In panels (a) and (b), the magnitude of the normal force from the floor is greater than Howard's weight. Hence, the net force points upward and so does Howard's acceleration. Once contact with the floor is broken, the only force acting on Howard is his weight, and he instantly begins accelerating downward.

Let's analyze the above jump in more detail

- v_y, in figure (c), is 9.9 mph = 14.6 ft/s
- h = 20 in = 1.67 ft
- What is the average acceleration? [Ans: 63.8 ft/s^2.]
- Can you write the above acceleration in units of g?



(a) Accelerating up from crouch (b) Straightening and swinging arms up (c) Feet lose contact with the floor (d) Rise and fall due to gravity alone

Imbalance of forces

Howard achieves an upward acceleration during the jump due to an imbalance of the forces on him.
Remember:

Imbalance of forces

- Using the previous equation, let's write the vertical launch acceleration of Howard and solve for ground reaction force (GRF):
- [Given that the mass of Howard is 8.28 slug]

$$a_{\mathrm{y.launch}} = \frac{G_y + W_y}{m}$$

or

$$G_y = ma_y - W_y$$

$$= (8.28 \text{ slug})(+63.8 \text{ ft/s}^2) - (-265 \text{ lb})$$

$$= ?$$

Another problem

Q. The coefficient of static friction for cleats on AstroTurf is 1.5. This places a limit on how quickly a player can accelerate without slipping.

a) What is the maximum acceleration with which 315-lb offensive lineman

Marcus Hall can burst off the line if he accelerates straight ahead?

b) How about for 210-lb Braxton Miller? Will his maximum acceleration

be more than, less than, or the same as that for Hall?

c) Is there anything they can do to increase their maximum acceleration?

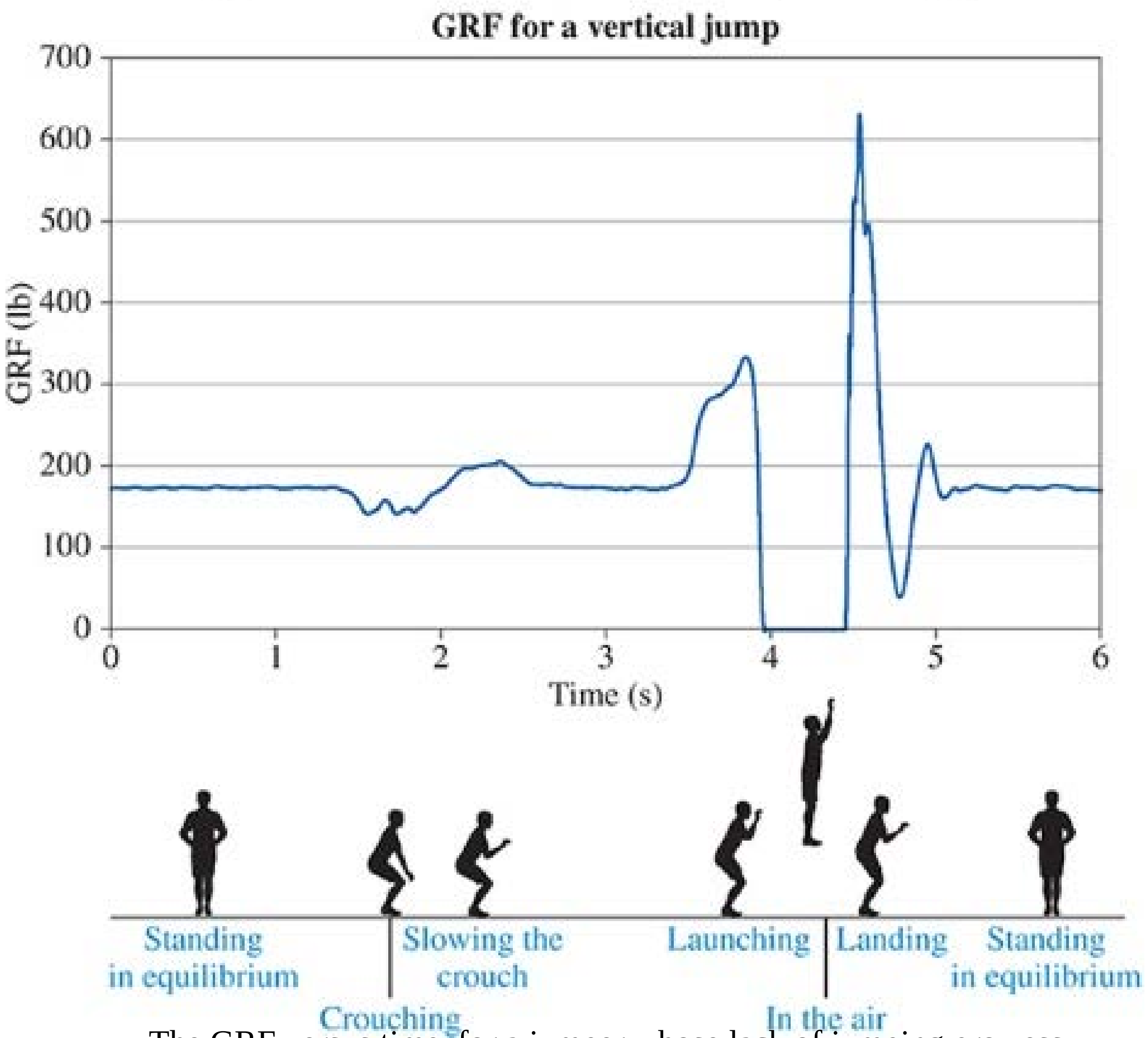
Problem 5, Page 76 of Lisa, Michael. *The Physics of Sports*. McGraw-Hill Higher Education, 2015

GRF: Peak Force

- We have noted that the average force exerted by Howard's legs during the jump is 793 lb – impressive indeed!
- However, this force is not constant during the jump – it grows with time and, depending on the jumper, can show some complicated wiggles.
- Figure on the next slide shows the GRF on a nonprofessional jumper, as he executes a jump.

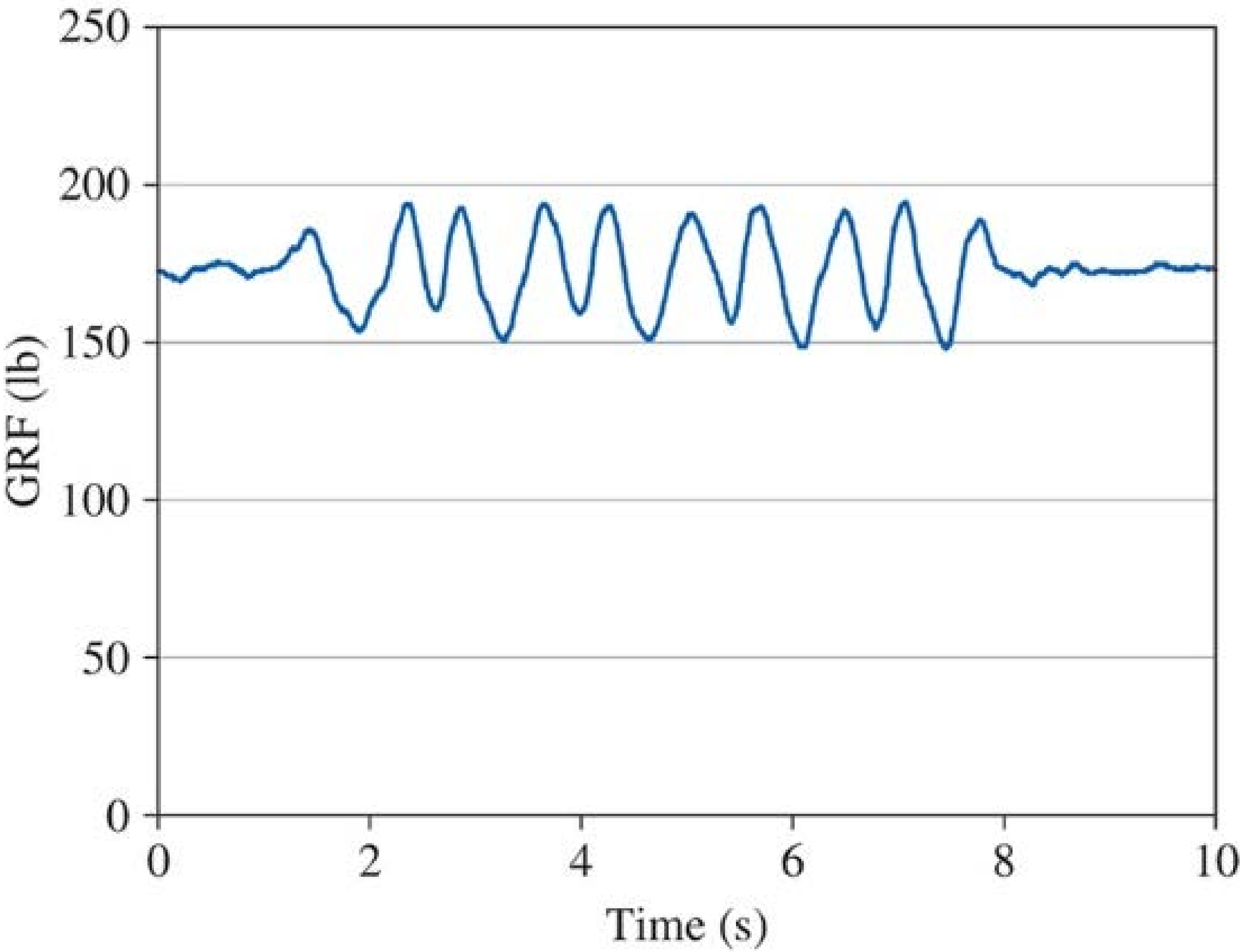
Lisa, Michael. *The Physics of Sports*. McGraw-Hill Higher Education, 20150220. VitalBook file.

For the first second or so, the jumper is stationary and not accelerating.1 He is in equilibrium; thus, the GRF is equal to his weight, 175 lb.
He begins his jump at about t = 3.5 s (corresponding to panel (a) of figure 3.4), and his feet leave the ground at about t = 3.9 s (panel (c) of figure 3.4).
The average force during this interval is about 250 lb, but the peak force occurs at about t = 3.8 s and is 350 lb, 40% higher.
It is reasonable to assume that Dwight Howard's peak force is likewise 40% higher than his average force of 793 lb – about 1100 lb, more than half a ton!



The GRF versus time, for a jumper whose lack of jumping prowess steered him toward an academic career (the author). The GRF is measured by a force plate - essentially a bathroom scale that can be read out via computer.

Lisa, Michael. *The Physics of Sports*. McGraw-Hill Higher Education, 20150220. VitalBook file.



What do you think is happening in the above diagram? What is the player doing?

Q. In the sport of curling, a player slides (or “throws”) a 40-lb granite stone along a sheet of ice. The thrower releases the stone at the “hogline,” which is 93’ away from the center of the intended target. The coefficient of kinetic friction between the stone and ice is $\mu K = 0.020$.

a) Draw a free body diagram of the stone as it passes the mid-way point on the sheet (long after the thrower has released it).

b) What is the net force on the stone (both magnitude and direction) at the mid-way point?

c) How fast (in mph) should the thrower release the stone at the hog line, in order to get it to stop in the center of the target on the other end of the sheet?

d) In competitive events, two “sweepers” rapidly brush the ice ahead of the stone, in order to tweak the friction coefficient slightly. If they make just a 5% mistake – i.e. they create ice with $\mu K = 0.021$ instead of 0.020– how far away from the center of the target will the stone stop, using the throw speed you found in part (c)?

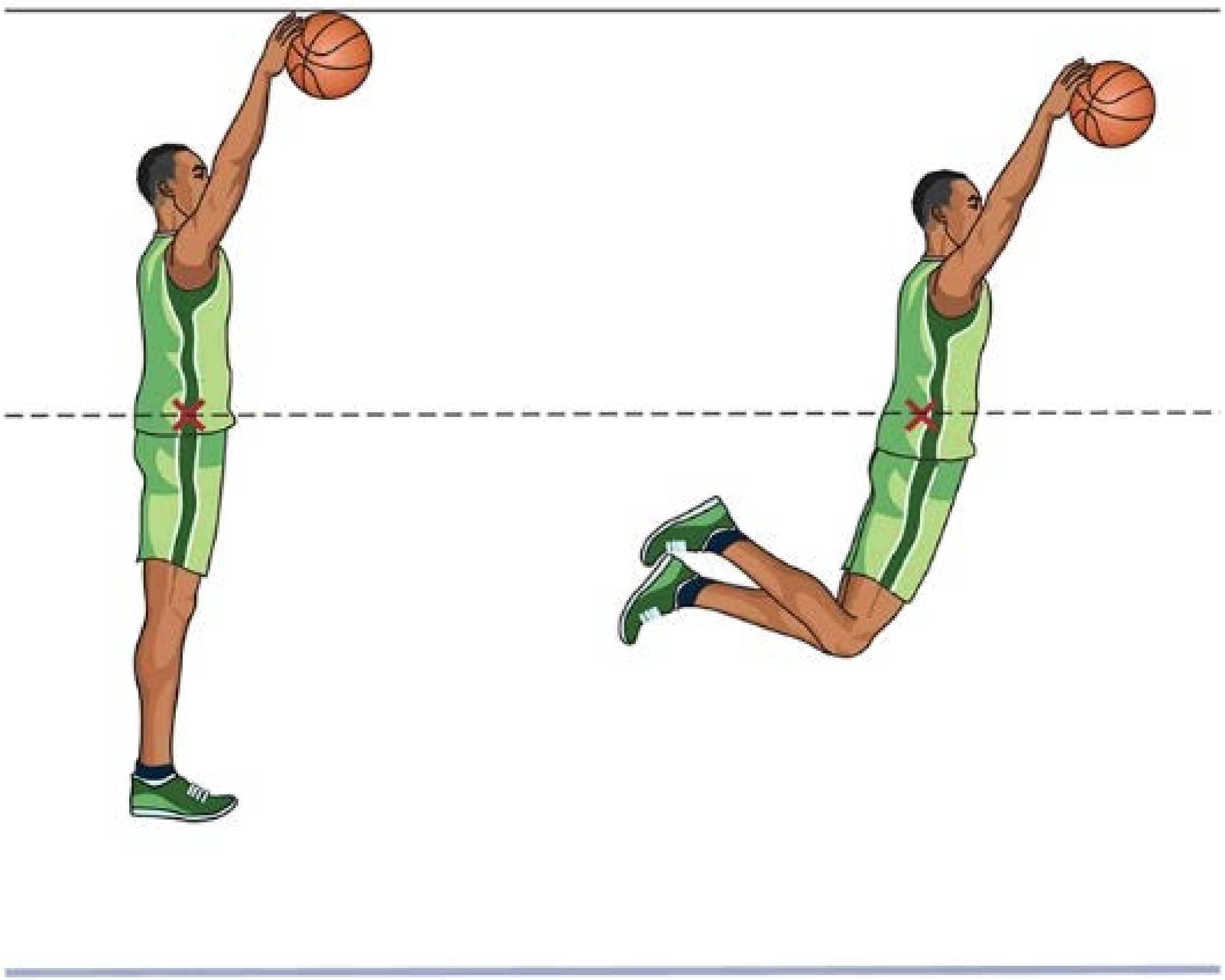
Another Problem

Q. I’m a scientist, so you can take it from me: people who compete in the Olympic event of skeleton are insane. With their chin often 3 inches from the ice, they rush down the track at speeds of 75 mph on a nearly weightless sled.

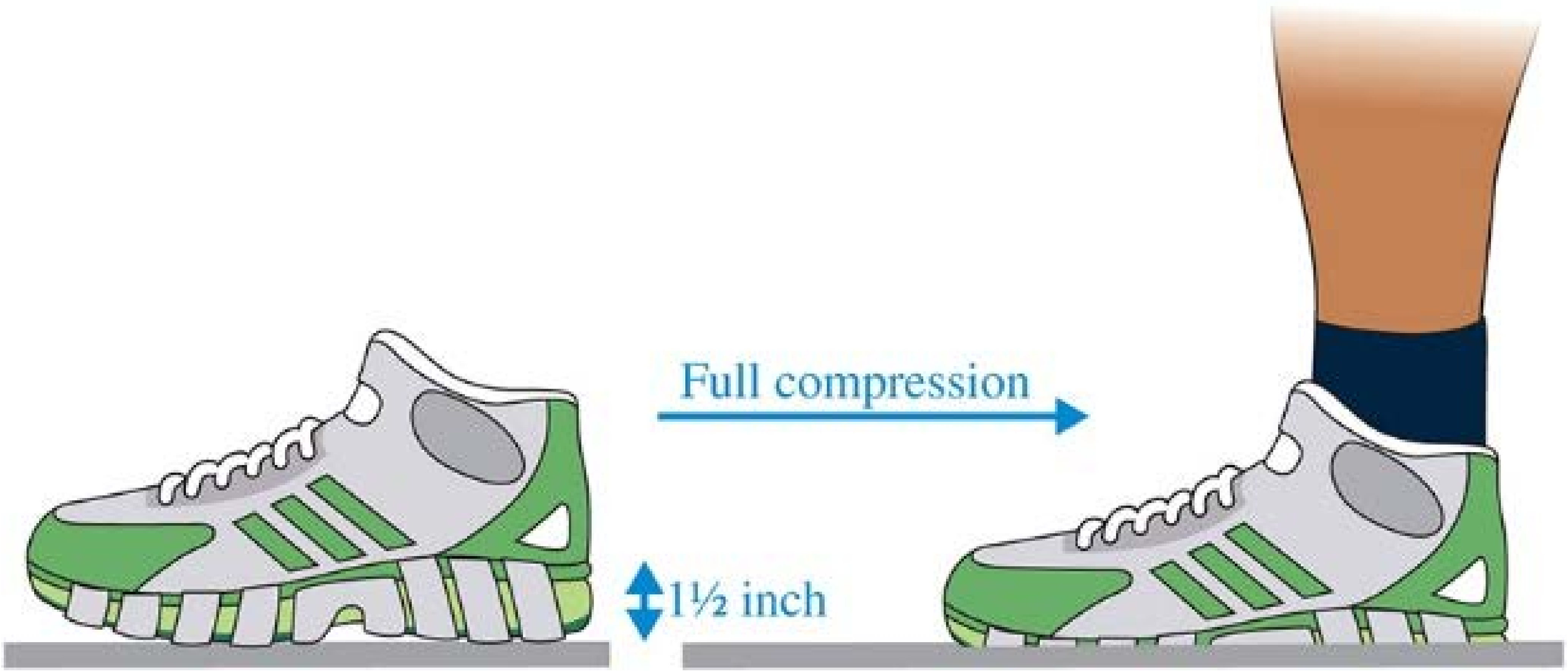
a) In what direction is the net force (if any) on the rider in the figure? Is she being pushed into her sled (to the right) or away from it (to the left) or not at all? Be sure to ask yourself whether this makes sense to you!

b) One turn in the Sochi Olympics had a radius of 42 m. At a speed of 75 mph, what is the total force on this 145-lb rider?

Solution

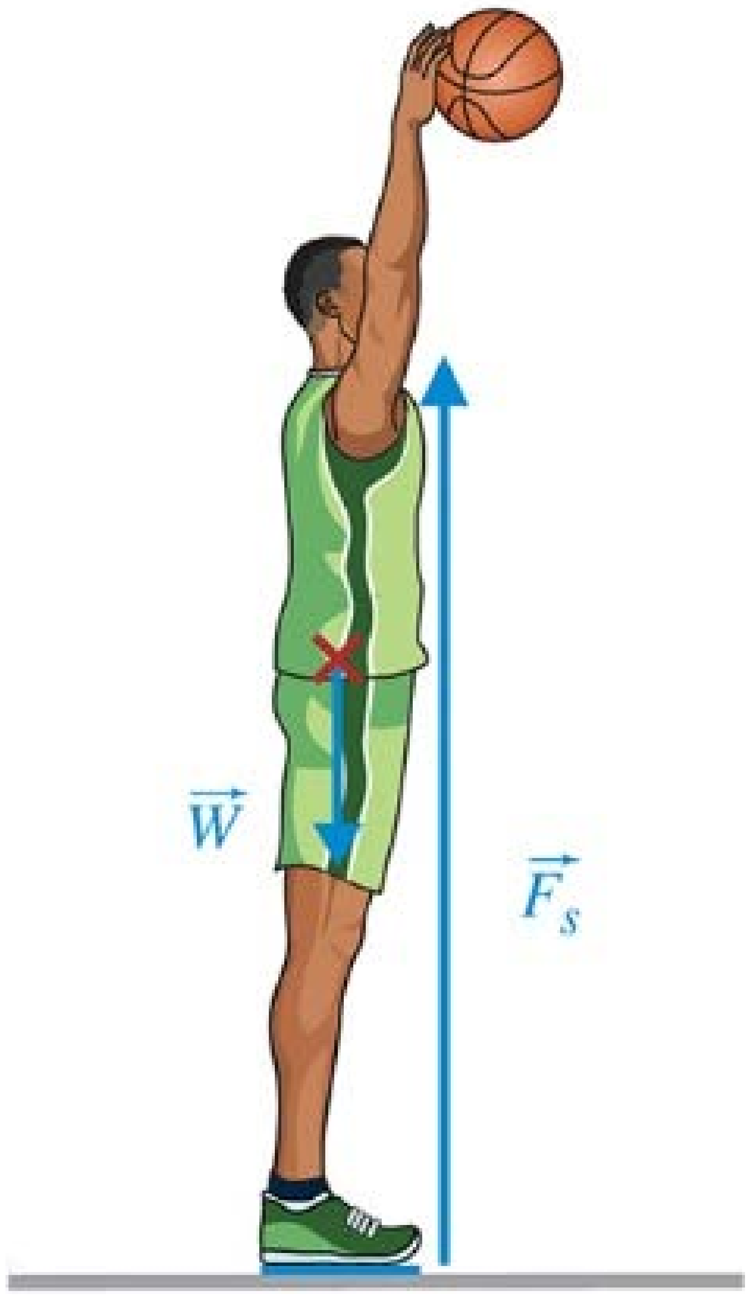


If he leaves the floor at 9.9 mph, Howard’s center of mass reaches a peak height of 40 in. In the jump to the right, he bends his knees. This causes his *feet* to go higher than they would have otherwise, but the peak height of his head and the ball are reduced.



Howard's Adidas shoes have a sole about 1.5 in. thick. If a player locks his knees and remains perfectly rigid, then his center of mass moves only as much as the soles compress. This distance cannot be more than the original thickness of the soles.

Free-body diagram for Dwight Howard as he lands. He is moving downward, but accelerating upward. The forces ***on*** Howard are his weight W and the upward force of his shoes F_s. The shoes are sketched in blue. We do not include forces on the shoes (such as the force of the floor) in a FBD of Howard.



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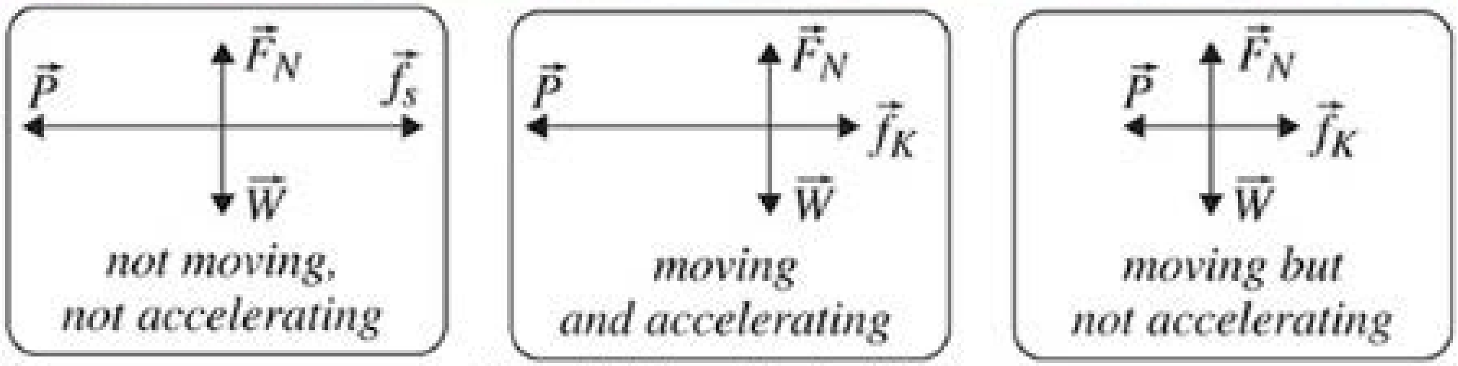
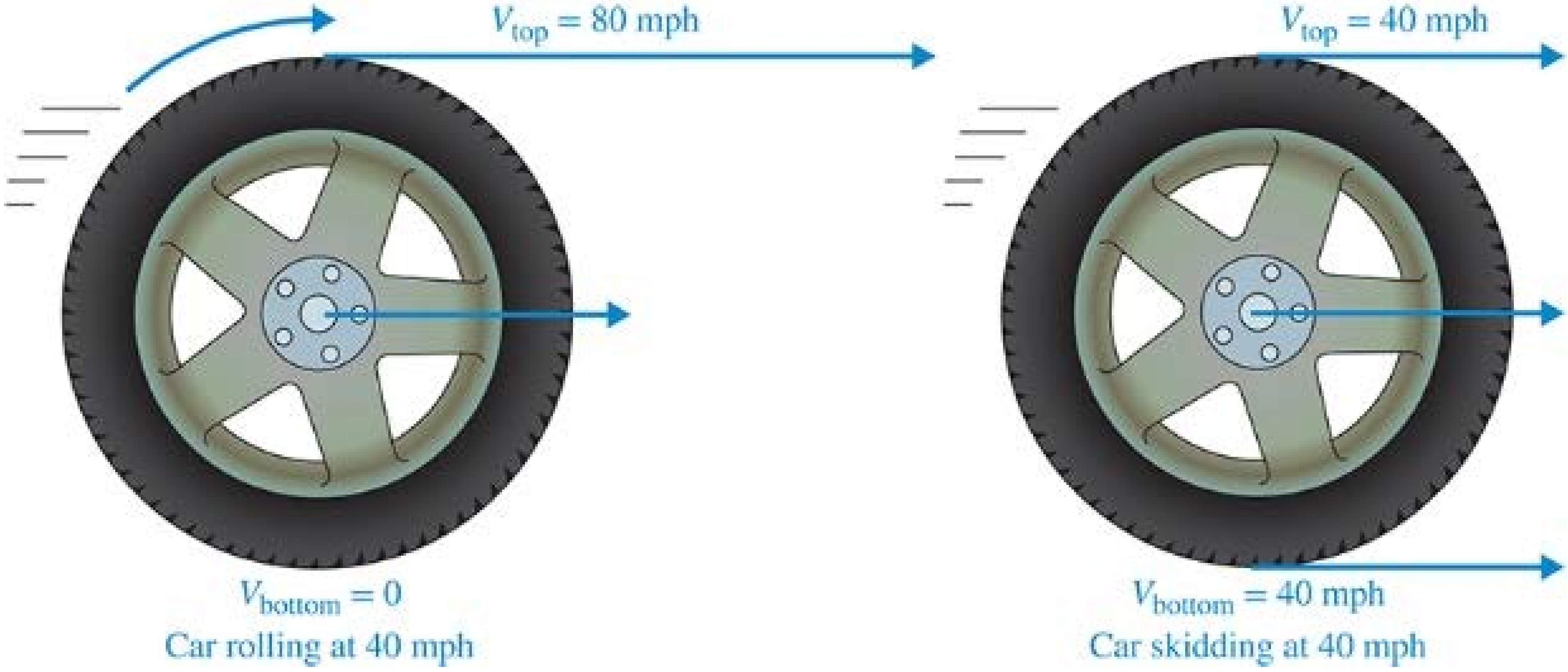
Based on Chapter 3, Mike Lisa “The Physics of Sports”

Washington Redskins nose tackle Chris Neild drives the sled with force *P* while guard Delvin Johnson weighs it down in training, May 2012. The tendency to slide is opposed by static friction f_s if the sled does not move, or kinetic friction f_k if it does. Because kinetic friction is smaller than static friction, the same push *P* will cause an acceleration, due to the force imbalance.





A car is traveling at 40 mph. If its wheel is rolling, the part of the tire touching the ground is instantaneously at rest.

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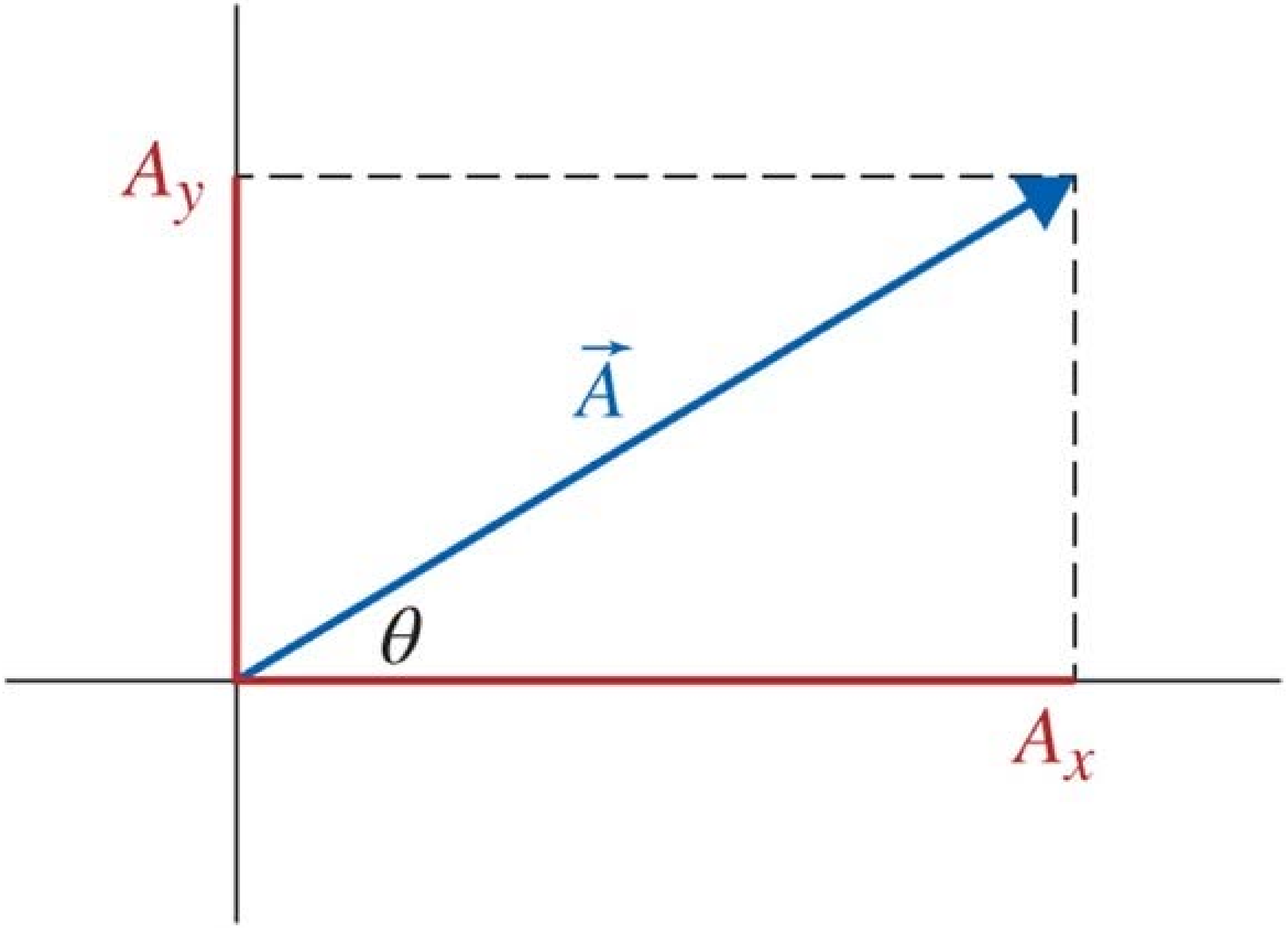
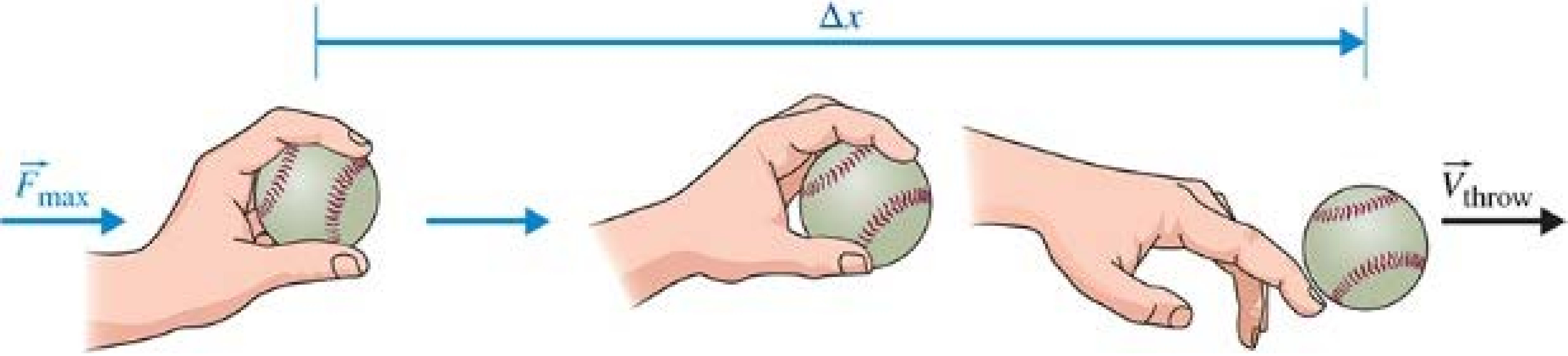
On the left is the FBD, showing all forces on Howard. On the right, the GRF is analyzed.


A_y
$\vec{A}$
θ
A_x



Description : A simplified picture of a baseball throw. A force F_{max} is applied to the ball and hand together, over a distance of Δx.

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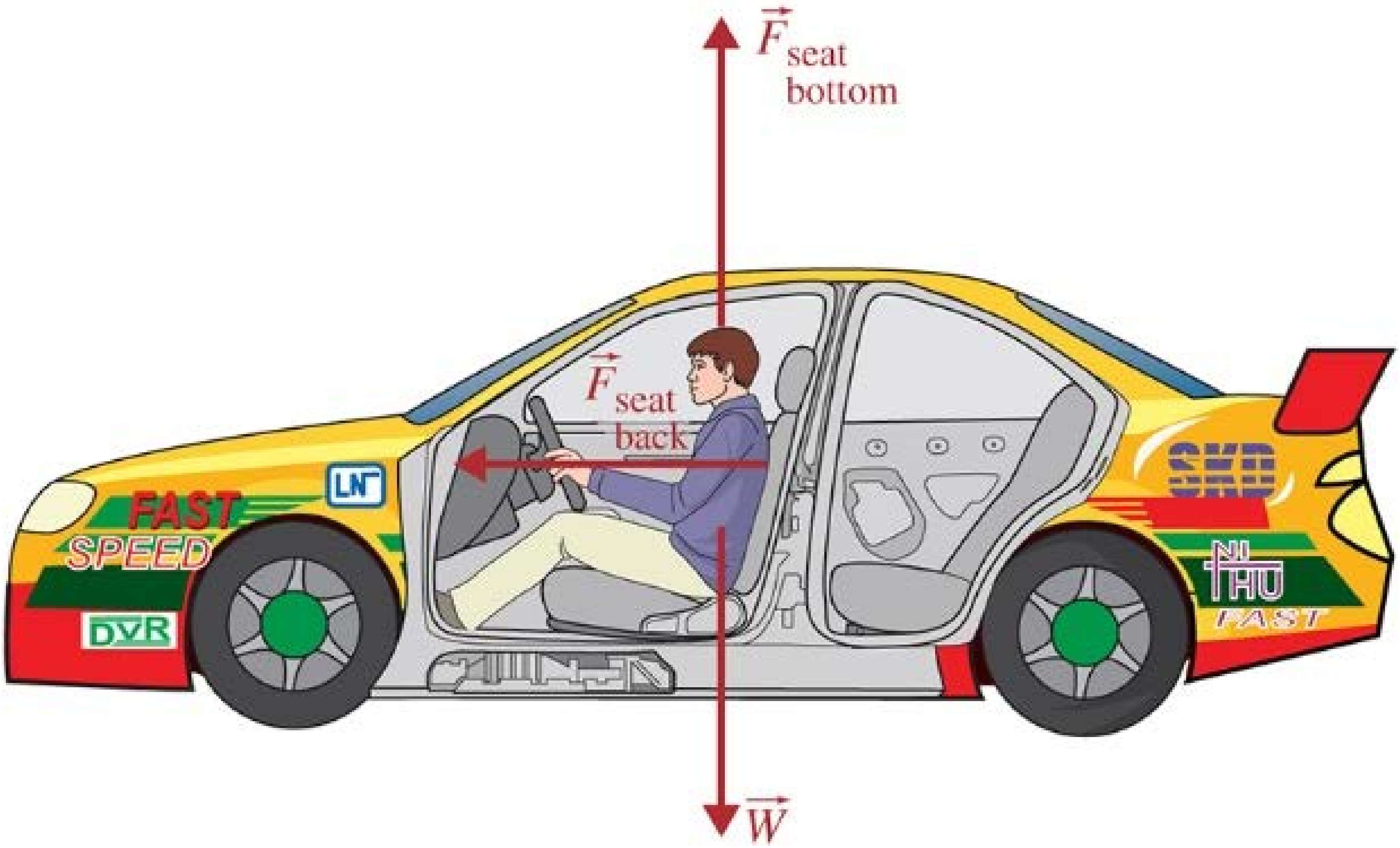

Dale Earnhardt Jr. accelerates along a straightaway. While he experiences a *sensation* of “heaviness” pulling him backward, there is in fact no backward force acting on him.

Canada vice-skip Kaitlyn Lawes delivers a stone during the semifinal of the Women's Curling competition between Great Britain and Canada from the Ice Cube Curling Centre, Coastal Clustre – XXII Olympic Winter Games in Sochi Russia, 2014. Separate free-body diagrams are shown for the stone and curler.

Group Projects

- Let’s make groups:
- Recommended:

1. Andrew, Julian, Theophile
2. Kristyn, Raymond, Nicolle Sahiba
3. Michael L, Tim, Ryan J
4. Michael J, Tori, Ryan R, Craig

References

- Skiing History Magazine, https://www.skiinghistory.org/skiing-history-magazine