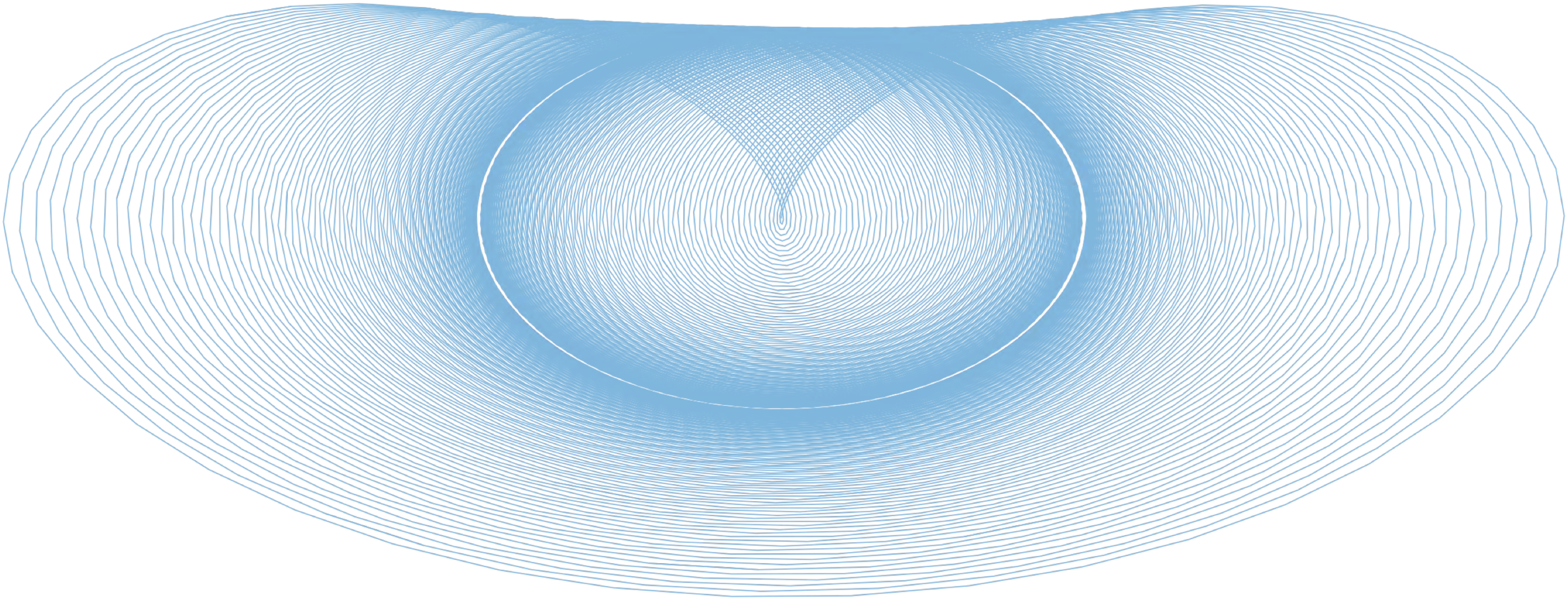
PHYS 1420 (F19)
Physics with Applications to Life Sciences



2019.09.23
Relevant reading:
Kesten & Tauck ch.4.4-4.5

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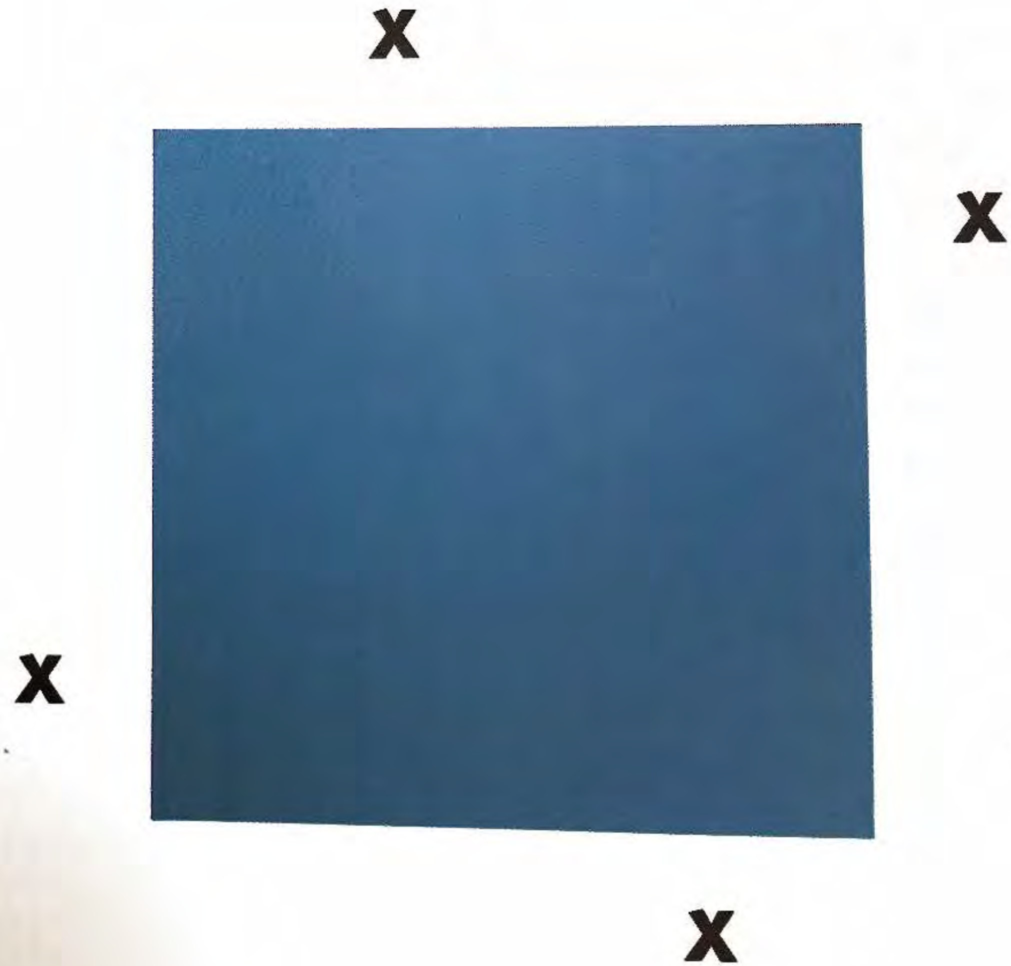
Ref. (re images):
Wolfson (2007), Knight (2017)

Can you draw a perfect square around the figure at right so that each side passes through one of the crosses and none of the sides touches the figure? There's just one hitch—the lines of the square you draw must not be parallel to those of the existing square.



Announcements & Key Concepts (re Today)

→ Online HW #3 posted and due Monday (9/23)

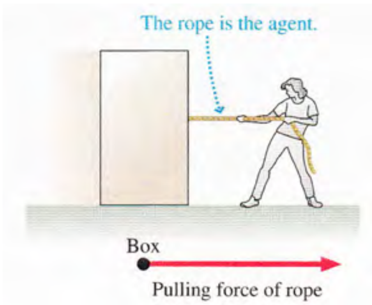
→ Written HW #1 posted and due 9/25 (in class at start of lecture)

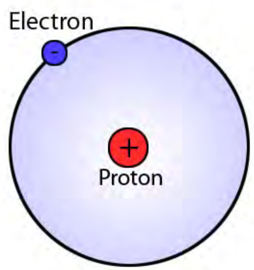
Some relevant underlying concepts of the day…

- Forces
- Newton’s Laws
- Equilibrium & Weight vs Mass → Newton’s Law of Gravitation
- Free-body diagrams

Review: Force

- Very fundamental concept in physics. Allows us to describe/understand how the motion of an object changes





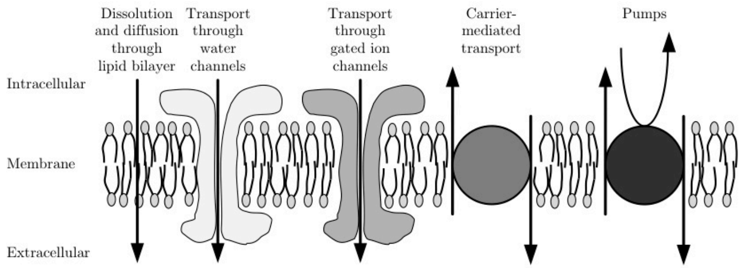
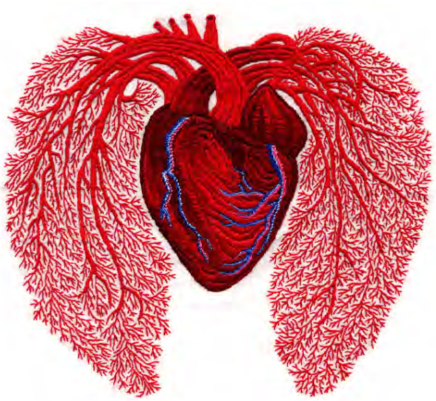
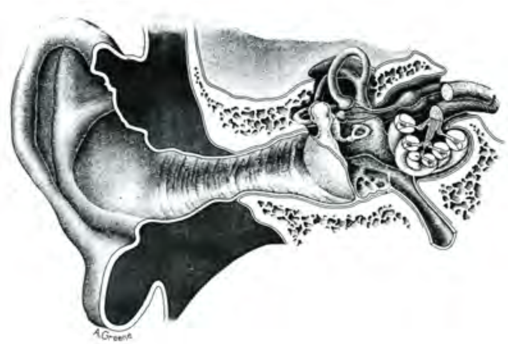


Figure 2.19

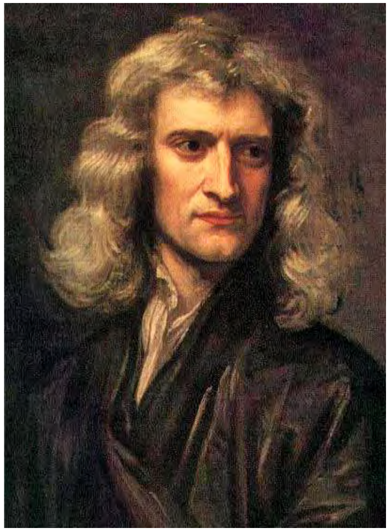




→ Consideration of forces is key to understanding all of it!

Newton's Laws

I. Newton (1643 -1727)



- Three (seemingly innocuous) rules for motion/forces

Newton's first law of motion: 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.

Newton's second law of motion: The rate at which a body's momentum changes is equal to the net force acting on the body:

$$\vec{F}_{\text{net}} = \frac{d\vec{p}}{dt} \qquad \text{(Newton's } 2^{\text{nd}} \text{ law)} \qquad (4.2)$$

$$\vec{F}_{\text{net}} = m\vec{a} \qquad \text{(Newton's } 2^{\text{nd}} \text{ law, constant mass)}$$

→ We will be using this one (a LOT)

Newton's third law of motion: If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.

- Wrapped up here are other key notions such as *inertia* and *momentum*
  (we'll be revisiting these plenty)

Wolfson

Interdisciplinary Connection: Force, Pressure, Ideal Gases, ...

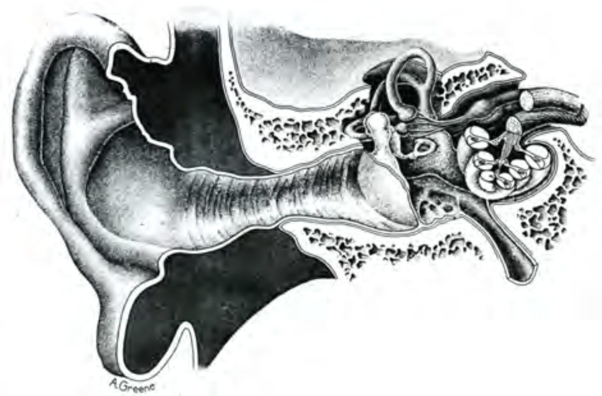
Kesten & Tauck ch.14

$$pV = NkT \quad \text{(ideal-gas law)}$$

Kesten & Tauck ch.11

$$p = \frac{F}{A} \quad \text{(pressure)}$$

- Pressure (a scalar, i.e., not a vector) is directly related to force
- But that must mean "area" is a vector too(!!?!)



Changes in pressure is how sound energy propagates

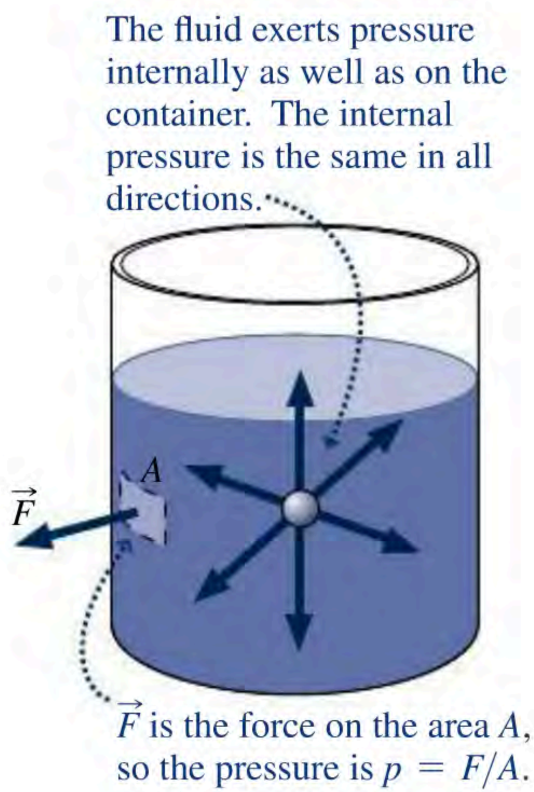


FIGURE 15.1 Pressure, the force per unit area, is exerted equally in all directions.

Looking ahead: (but not today)

- Area can be considered a vector
- Can you "divide" two vectors?

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Interdisciplinary Connection: Force, Pressure, Ideal Gases, ...

→ Basic concepts stemming from Newtonian mechanics apply to fluids and gases too

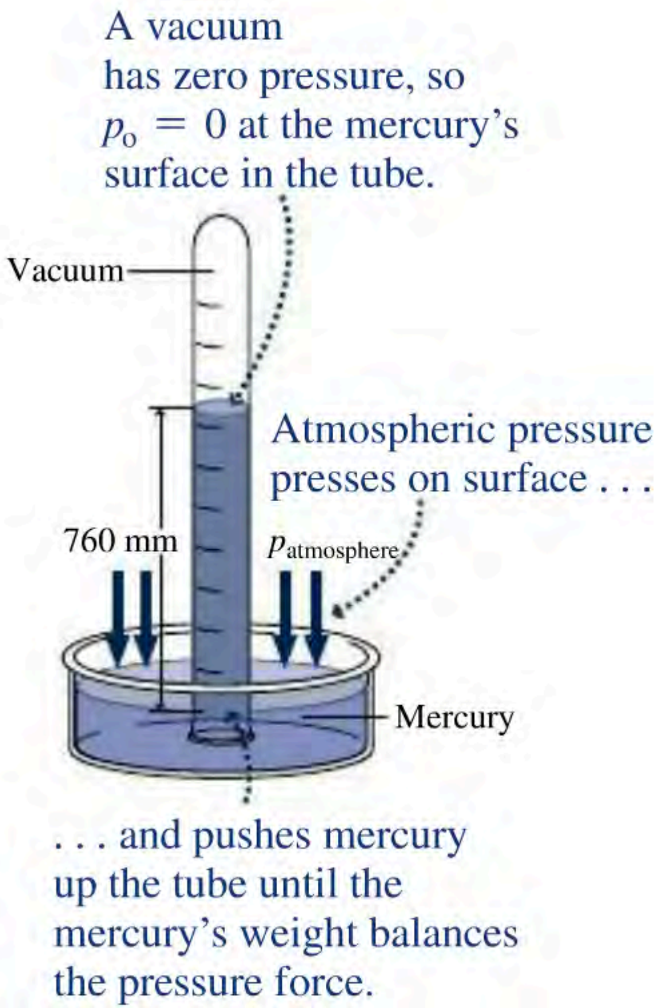


FIGURE 15.4 A mercury barometer.

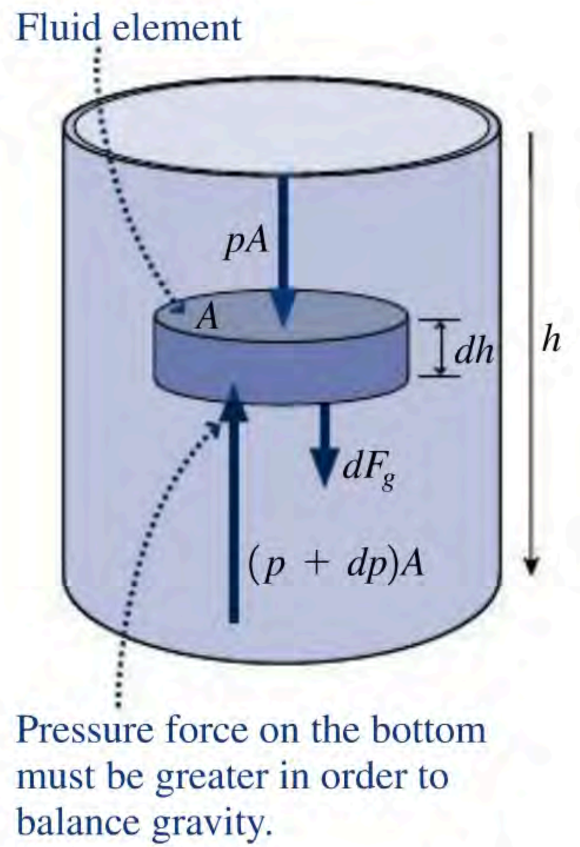
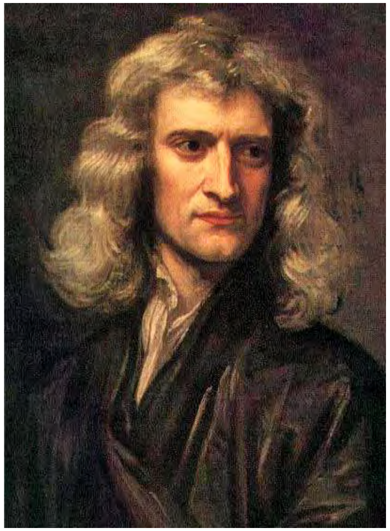


FIGURE 15.3 Forces on a fluid element in hydrostatic equilibrium.

Newtonian Mechanics

I. Newton (1643 -1727)



Newton's 2nd Law
(const. mass)

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

Product of object's mass and its acceleration; not a force

Net force: the vector sum of all real, physical forces acting on an object

Equal sign indicates that the two sides are mathematically equal — but that doesn't mean they're the same physically. Only $\vec{F}_{\text{net}}$ involves physical forces.

→ Forces are telling you something about how something else changes (or in some cases, not change)!

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Static Equilibrium

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

Product of object's mass and its acceleration; not a force.

Net force: the vector sum of all real, physical forces acting on an object

Equal sign indicates that the two sides are mathematically equal — but that doesn't mean they're the same physically. Only $\vec{F}_{net}$ involves physical forces.

→ Situations where all forces balance one another out such that nothing changes [i.e., $a = 0$]

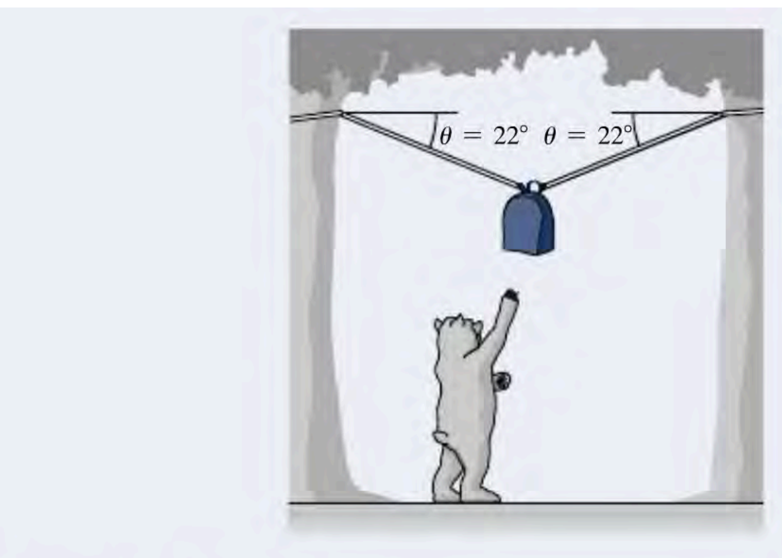

FIGURE 5.3 Bear precautions.

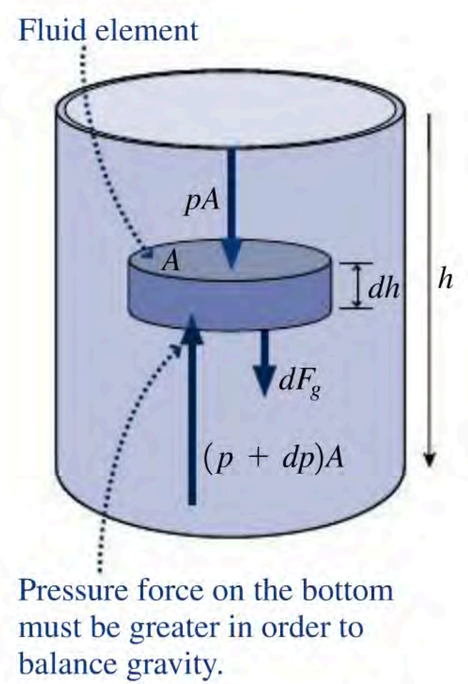

FIGURE 15.3 Forces on a fluid element in hydrostatic equilibrium.

Free-Body Diagrams

- Useful to set up problems and characterize the relevant forces at play

TACTICS 4.1 **Drawing a Free-Body Diagram**

Drawing a free-body diagram, which shows the forces acting on an object, is the key to solving problems with Newton's laws. To make a free-body diagram:

1. Identify the object of interest and all the forces acting on it.
2. Represent the object as a dot.
3. Draw the vectors for *only* those forces acting *on* the object, with their tails all starting on the dot.

Figure 4.11 shows two examples where we reduce physical scenarios to free-body diagrams. We often add a coordinate system to the free-body diagram so that we can express force vectors in components.

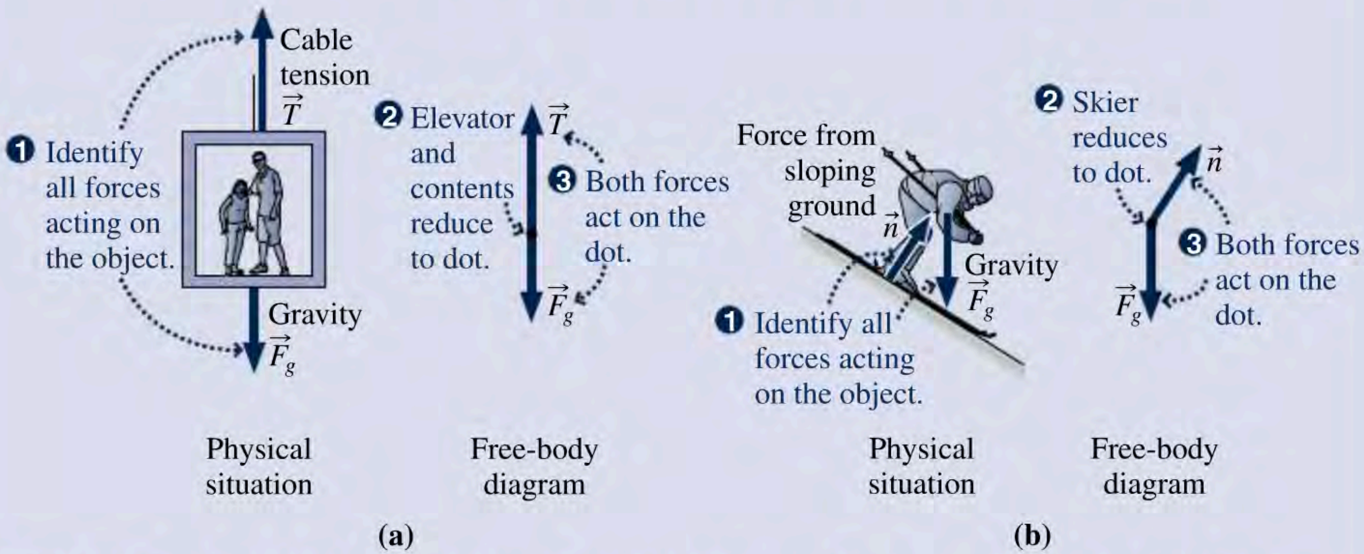

FIGURE 4.11 Free-body diagrams. (a) A one-dimensional situation like those we discuss in this chapter. (b) A two-dimensional situation. We'll deal with such cases in Chapter 5.

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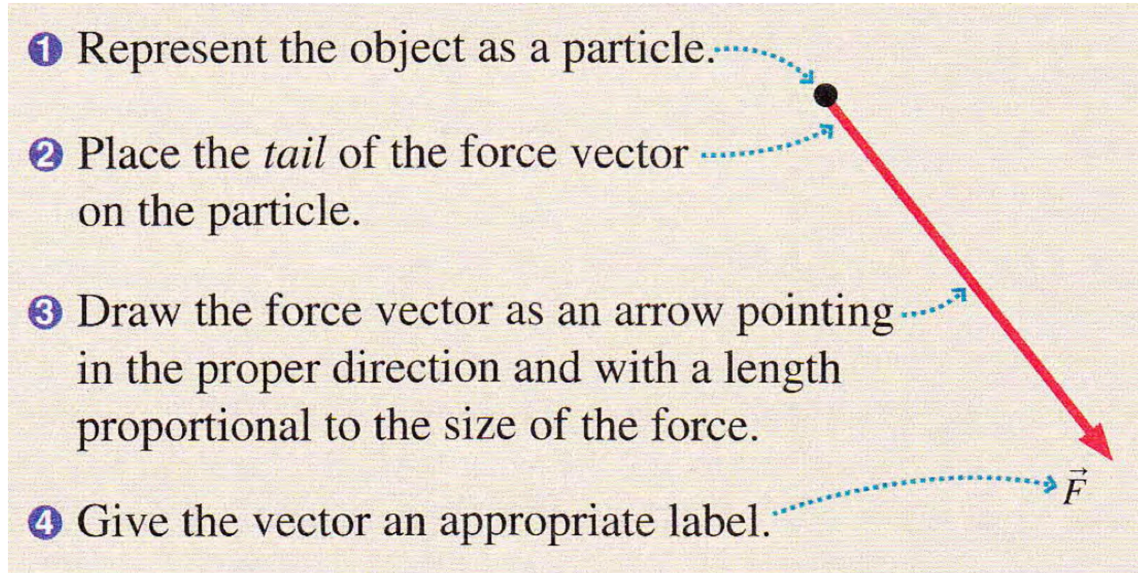
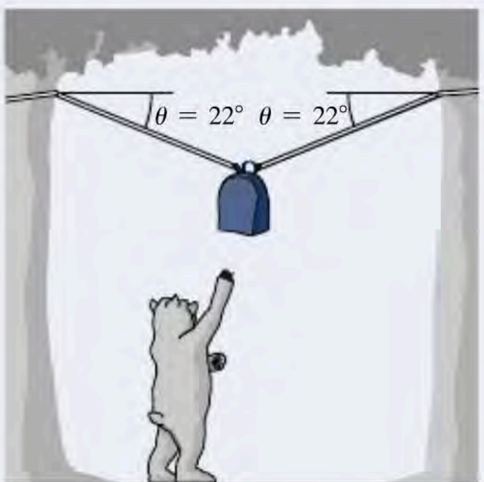
Free-Body Diagrams



Knight (2013)

Note: Be aware of simplifications being made (e.g., ignoring torque on the backpack)



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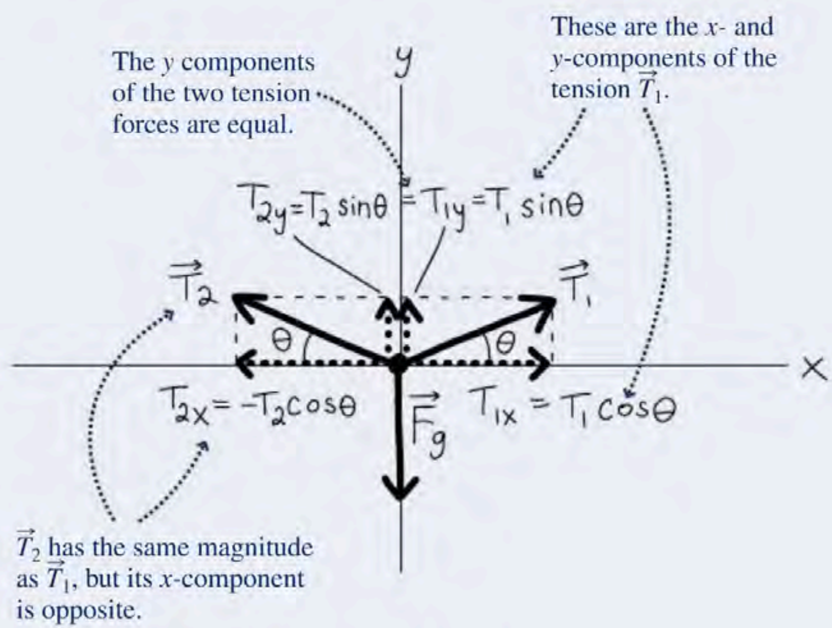

FIGURE 5.4 Our free-body diagram for the pack.

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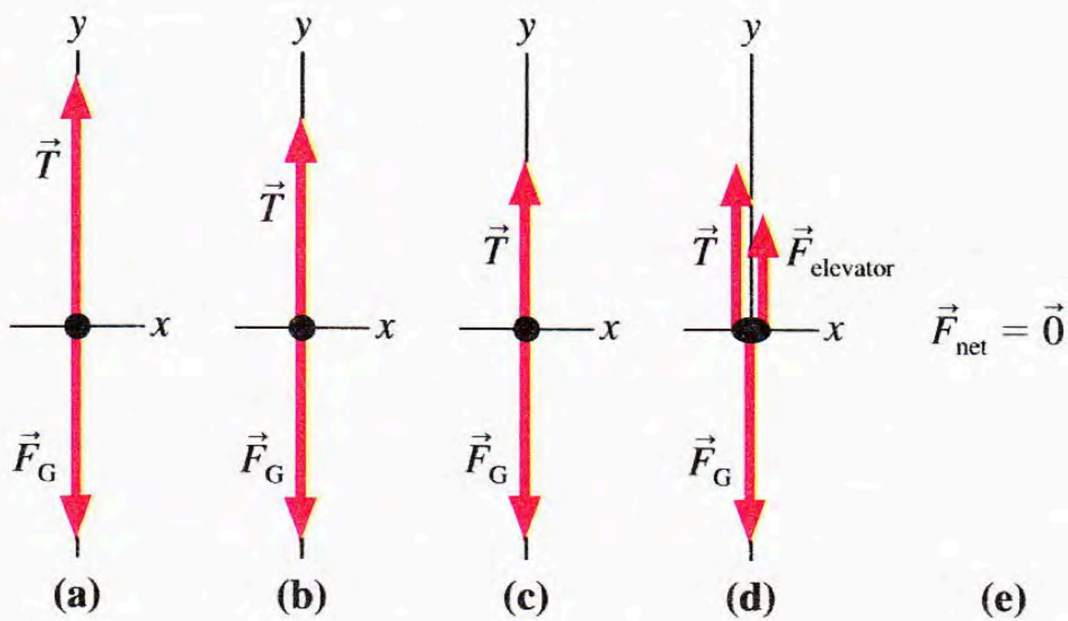
Ex.

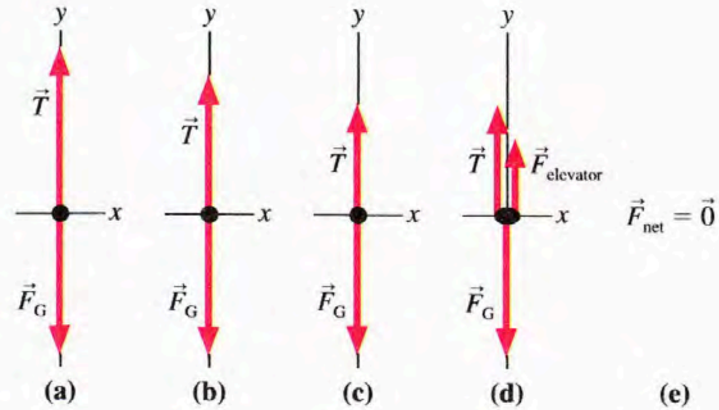
STOP TO THINK 5.5 An elevator suspended by a cable is moving upward and slowing to a stop. Which free-body diagram is correct?



Knight (2013)

Ex. (SOL)

STOP TO THINK 5.5 An elevator suspended by a cable is moving upward and slowing to a stop. Which free-body diagram is correct?



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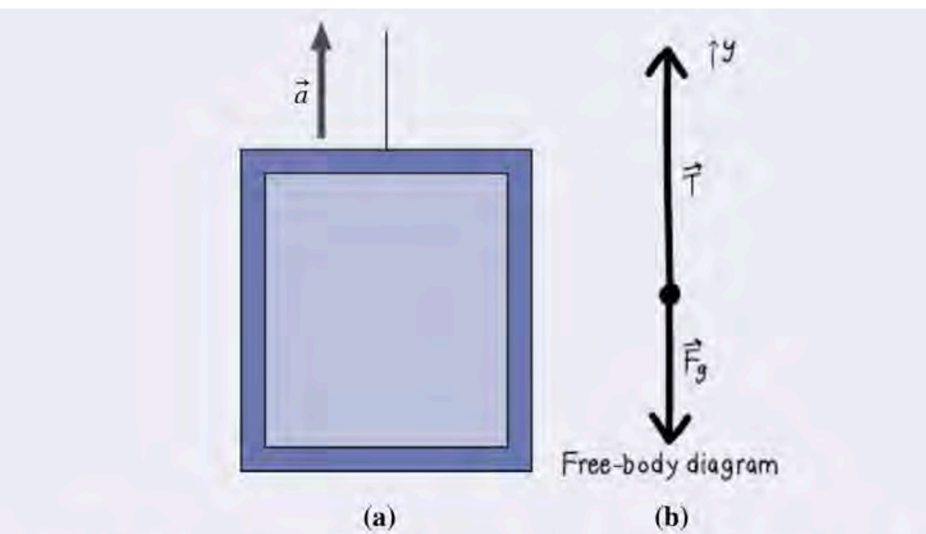

FIGURE 4.12 The forces on the elevator are the cable tension $\vec{T}$ and gravity $\vec{F}_g$.

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Knight (2013)

Force

- Force has units!

Units in $F = ma$

Systems of Units	Force	Mass	Acceleration
Mks	newton (nt)	kilogram (kg)	meter/sec^2
Cgs (Gaussian)	dyne	gram (gm)	cm/sec^2
Engineering	pound (lb)	slug	ft/sec^2

- 1 newton (N) in SI units is 1 $\mathrm{kg\ m/s^2}$
- 1 pound (lb) is 4.45 N

→ Wait (pun!). Is weight a force or a mass?

Resnick & Halliday (1966)

A Starting Point (re Newton): Weight vs Mass

- Intuitive (kinda). Implicit/explicit connection to gravity

Note: Use of exponential notation here (compact way to deal w/ large range of #s)

SOME MEASURED MASSES

Object	Mass (kg)
Our galaxy	2.2×10^{41}
The sun	2.0×10^{30}
The earth	6.0×10^{24}
The moon	7.4×10^{22}
Mass of all the water in the oceans	1.4×10^{21}
An ocean liner	7.2×10^{7}
An elephant	4.5×10^{3}
A man	7.3×10^{1}
A grape	3.0×10^{-3}
A tobacco mosaic virus	6.7×10^{-10}
A speck of dust	2.3×10^{-13}
A penicillin molecule	5.0×10^{-17}
A uranium atom	4.0×10^{-25}
A proton	1.7×10^{-27}
An electron	9.1×10^{-31}

- *Mass* (m) is some sort of inherent property of matter

- The range of masses is HUGE

$$\vec{w} = m\vec{g} \qquad \text{(weight)}.$$

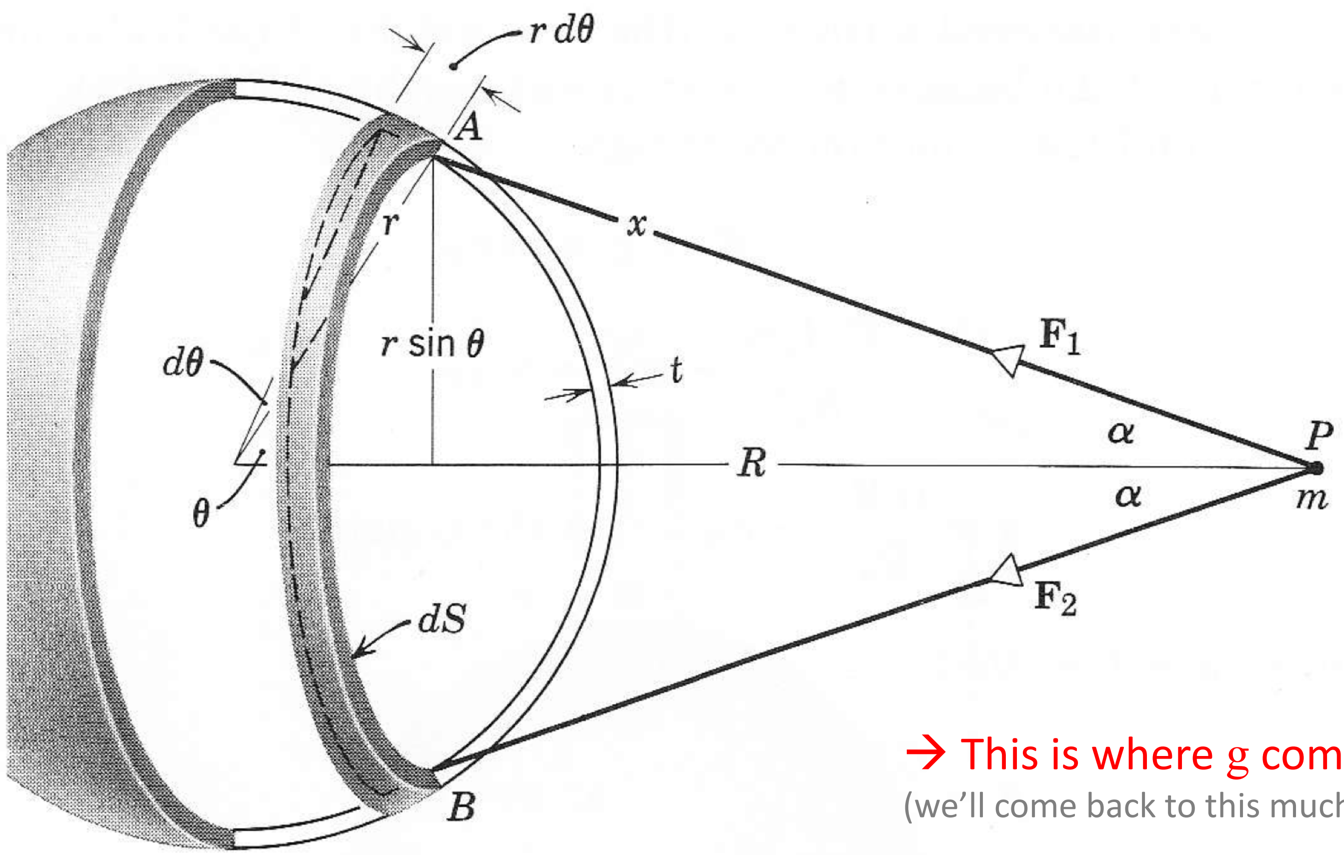
So weight ties mass and gravity together

Resnick & Halliday (1966)

A Starting Point (re Newton): Weight vs Mass

Remember: One of Newton's big contributions was to give insight into gravity

→ Gravity pervades every aspect of our "everyday lives" (e.g., getting "up" in the morning)



→ This is where g comes from!

(we'll come back to this much later)

Fig. 16–6 Gravitational attraction of a section dS of a spherical shell of matter on a particle of mass m.

Resnick & Halliday (1966)

$$\vec{F}_G = \vec{F}_{\text{planet on } m} = \left(\frac{GMm}{R^2}, \text{ straight down}\right) = (mg, \text{ straight down})$$

FIGURE 6.6 Newton's law of gravity.

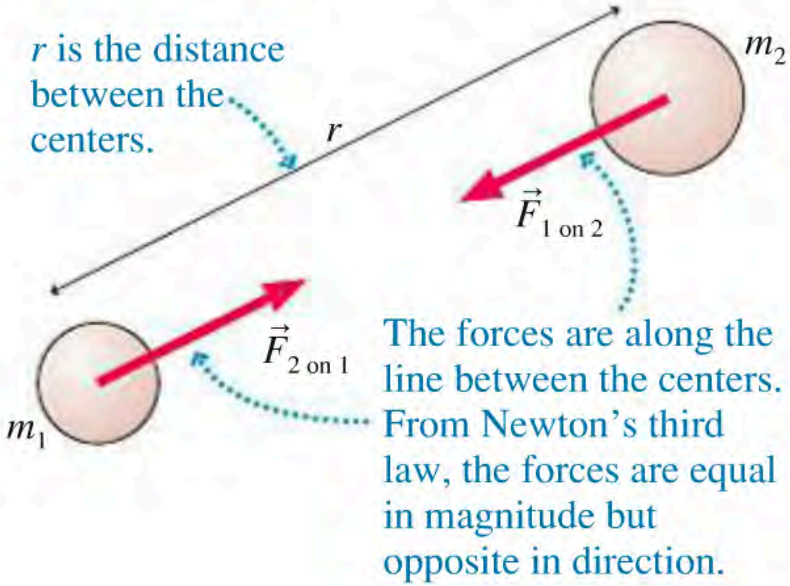
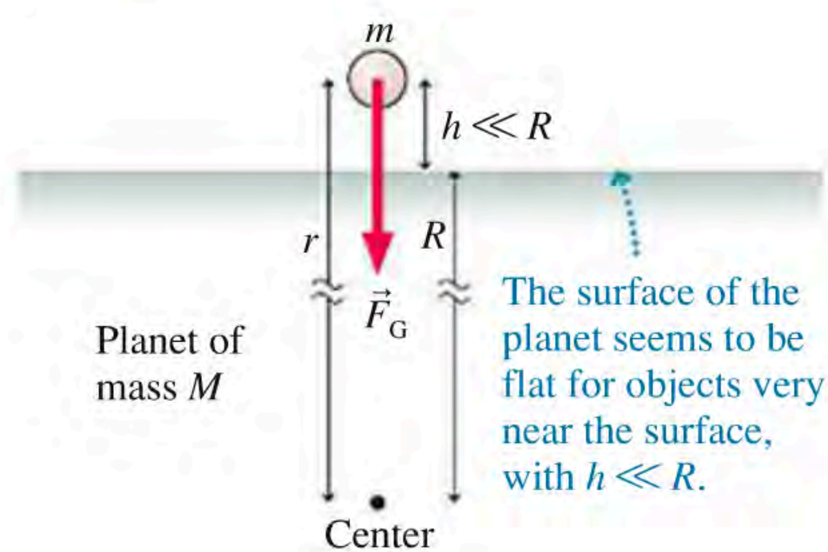


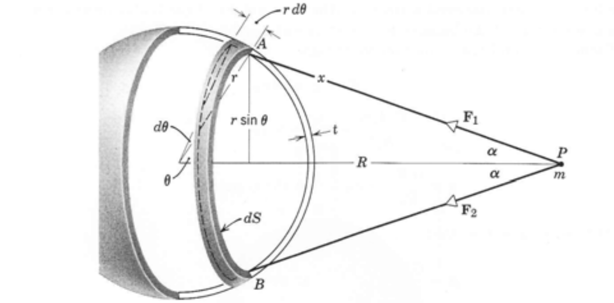
FIGURE 6.7 Gravity near the surface of a planet.



Knight (2013)

A Starting Point (re Newton): Weight vs Mass

- The acceleration due to gravity (i.e., g) isn't strictly 9.81 m/s^2 per se...



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Variation of g with Altitude at 45° Latitude

Altitude, meters	g, meters/sec^2	Altitude, meters	g, meters/sec^2
0	9.806	32,000	9.71
1,000	9.803	100,000	9.60
4,000	9.794	500,000	8.53
8,000	9.782	1,000,000[1]	7.41
16,000	9.757	380,000,000[2]	0.00271

[1] Typical satellite orbit altitude (= 620 miles).
[2] Radius of moon's orbit (= 240,000 miles).

Resnick & Halliday (1966)

A Starting Point (re Newton): Weight vs Mass

- So what about astronauts on the International Space Station (ISS)?

- ISS orbit is between 330-435 km
- So g is kinda close to what it is on earth…

→ So how/why are they "weightless"?

Variation of g with Altitude at 45° Latitude

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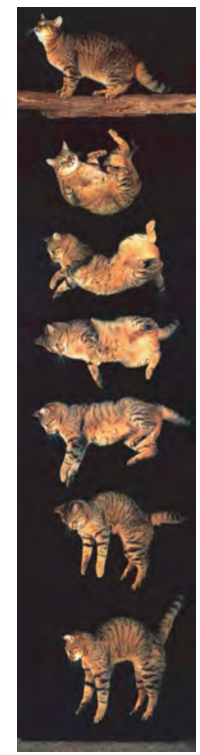
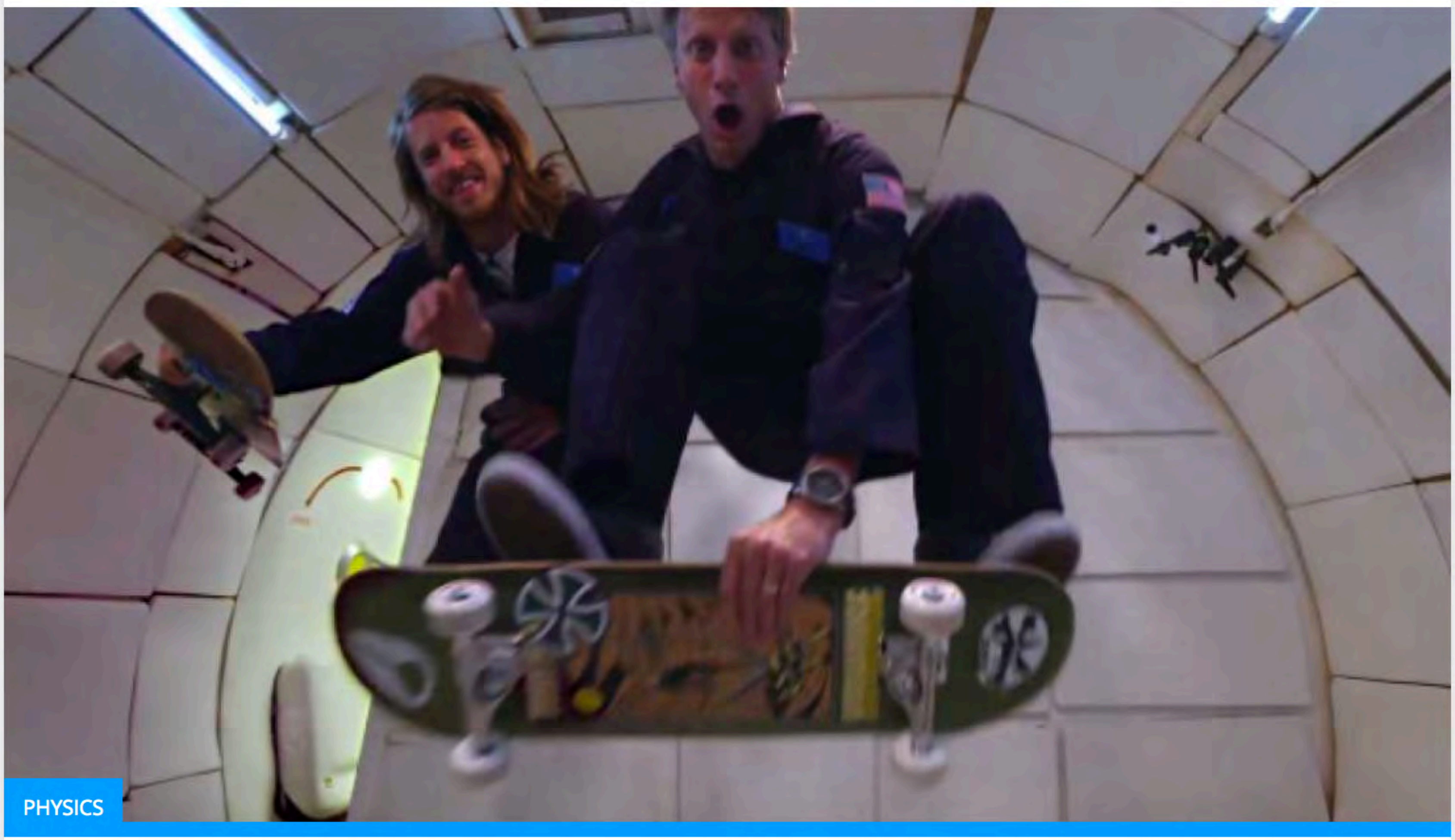
Gravity (2013)



→ Free fall
(we'll come back to this shortly)

Tony Hawk Tries Out Some Weightless Skateboarding On "The Vomit Comet"



http://www.iflscience.com/physics/tony-hawk-tries-out-some-weightless-skateboarding-vomit-comet/