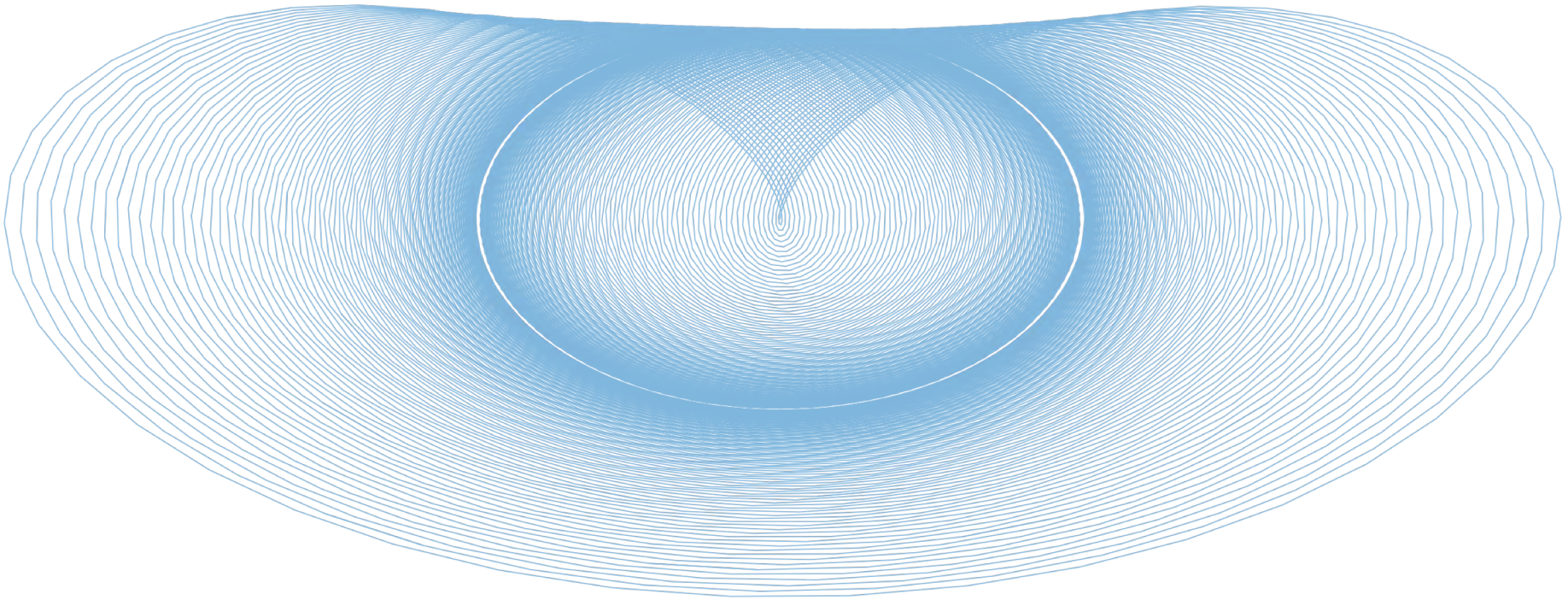
PHYS 1420 (F19)
Physics with Applications to Life Sciences



2019.09.30

Relevant reading:
Kesten & Tauck ch.5.1-5.3

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

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

A bear, starting from the point P, walked one mile due south.
Then he changed direction and walked one mile due east.
Then he turned again to the left and walked one mile due north,
& arrived exactly at the point P he started from.

→ What was the color of the bear?

Announcements & Key Concepts (re Today)

→ Online HW #4 posted and due Wednesday 10/2

→ Read McCullough (2016 Biophys. J.) for tutorial tomorrow (10/1)

→ Midterm exam on Monday 10/21 (*after* Reading Week)

Some relevant underlying concepts of the day…

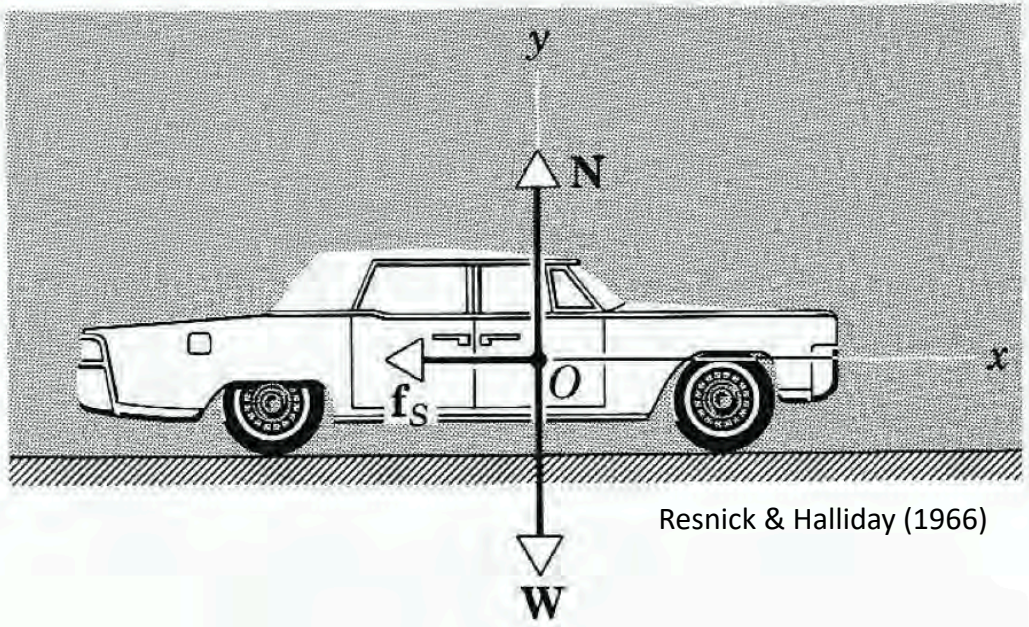
- Notion of *resistive* forces
- Microscopic and conventional views on *friction*
- Static vs Kinetic (vs "Rolling")

Friction



→ If at constant speed on highway, why the need to push the gas pedal?

Friction



Resnick & Halliday (1966)

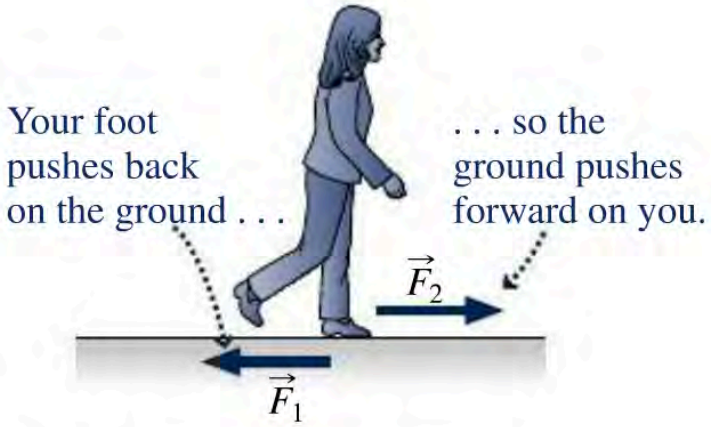


FIGURE 5.21 Walking.

→ Without friction, it'd be hard to make it anywhere in the first place!

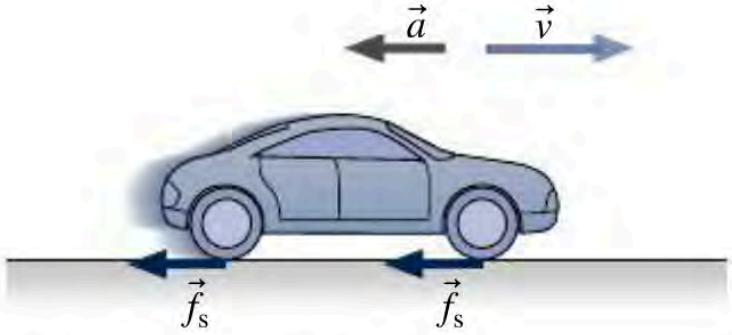
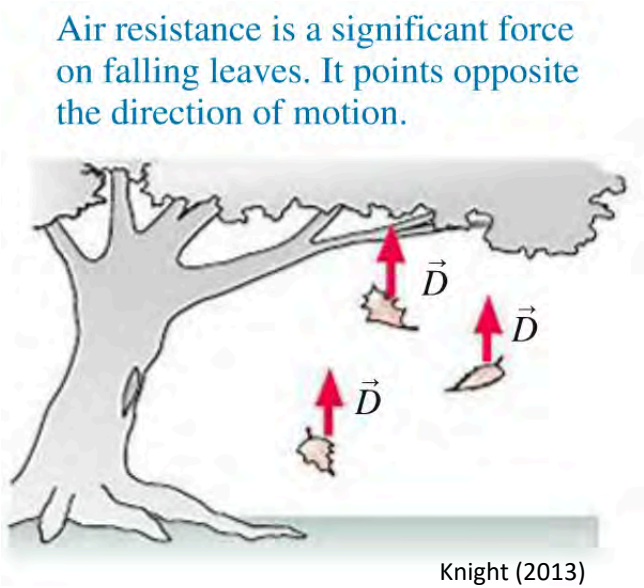


FIGURE 5.22 Friction stops the car.

Wolfson

Friction

- "Friction" comes in many forms....

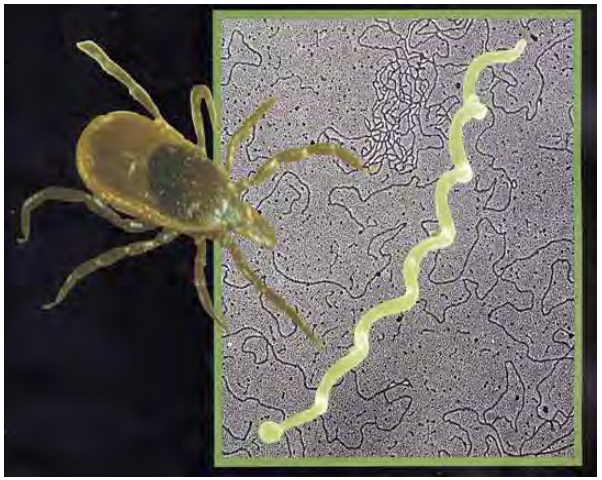


Knight (2013)



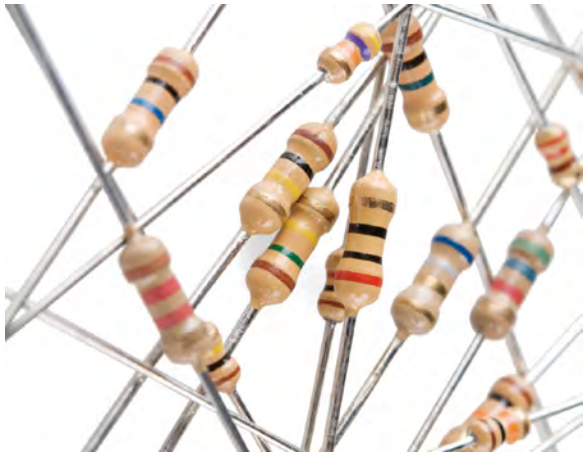
Viscosity

Drag → Bacterial motion



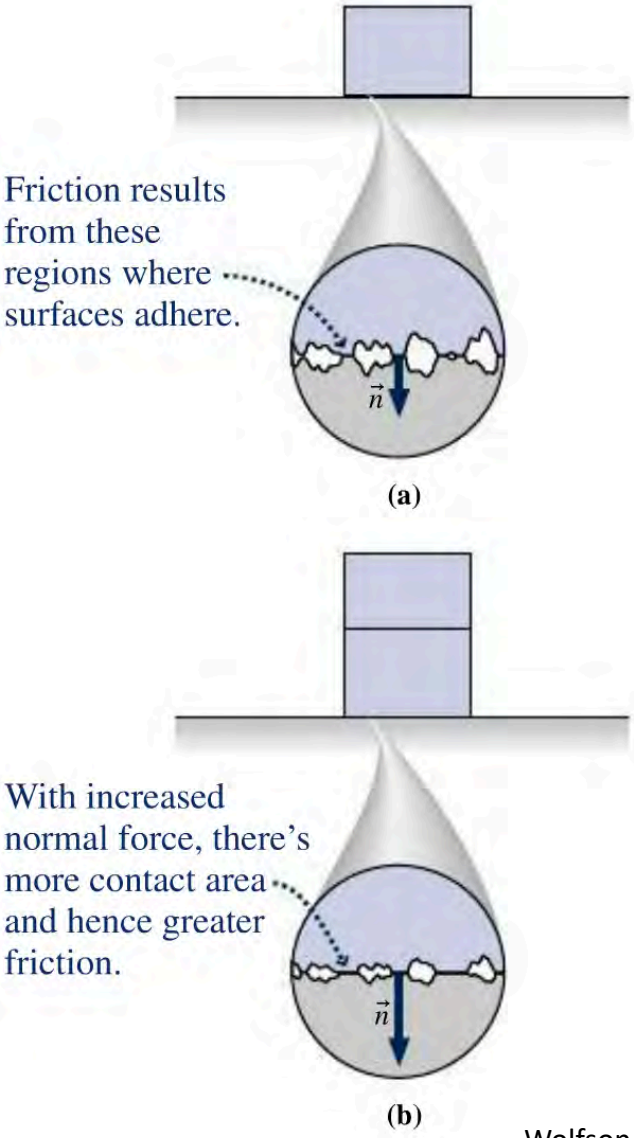
Ticks → Spirochetes → Lyme Disease

Electrical resistance



→ Focus initially on contact friction

Friction



Wolfson

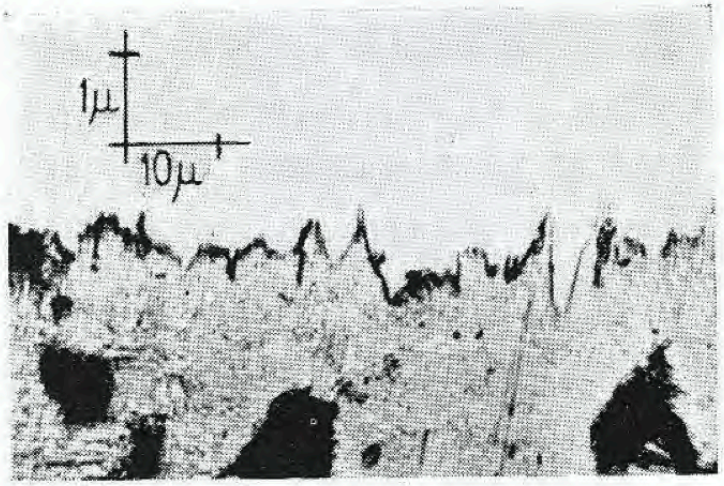


Fig. 6–2 A highly magnified view of a section of a finely polished steel surface. The section was cut at an angle so that vertical distances are exaggerated by a factor of ten with respect to horizontal distances. The surface irregularities are several thousand atomic diameters high. From *Friction and Lubrication of Solids*, by F. P. Bowden and D. Tabor, Clarendon Press, 1950.

Resnick & Halliday (1966)

Friction

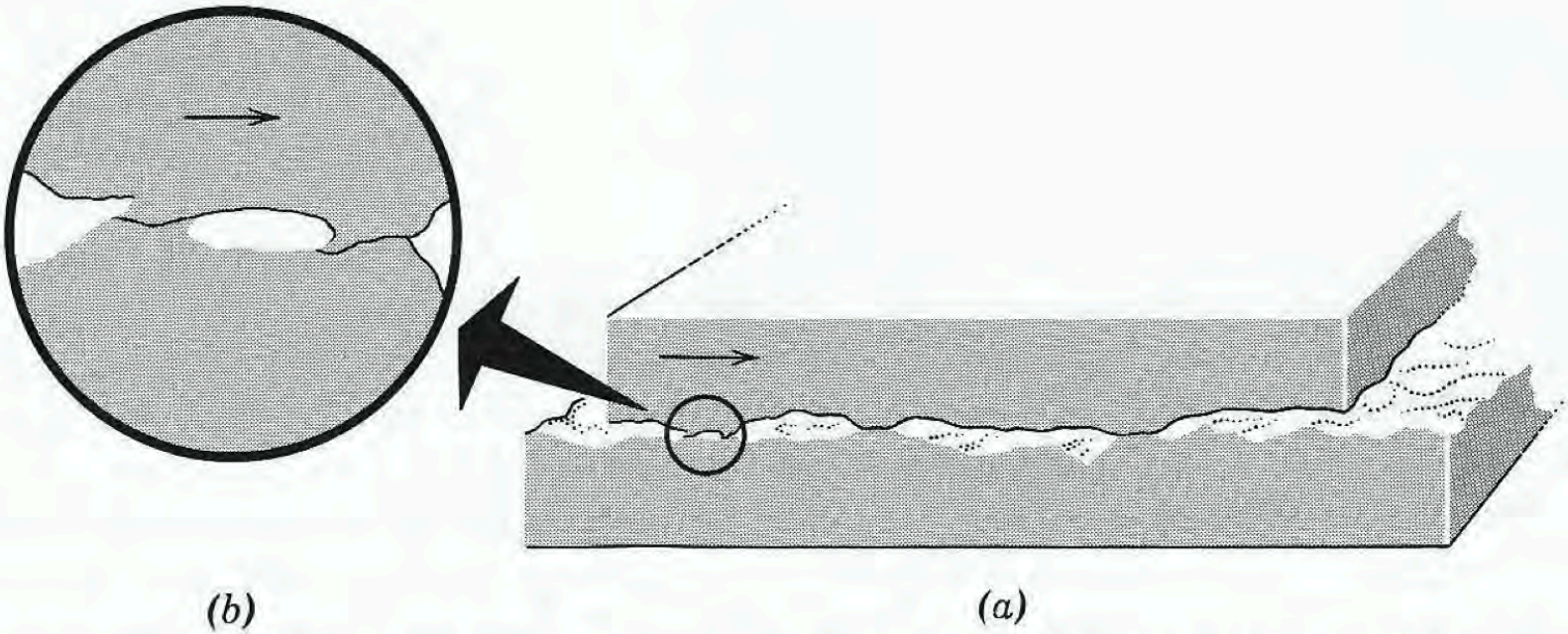


Fig. 6–3 Sliding friction. (*a*) The upper body is sliding to the right over the lower body in this enlarged diagram. (*b*) A further enlarged view showing two spots where surface adhesion has occurred. Force is required to break these welds apart and maintain the motion.

→ "break these welds apart" is a bit vague, but alludes to molecular considerations still not entirely all that well understood....

Resnick & Halliday (1966)



June 30, 2016 issue of Nature

LETTER

676 | NATURE | VOL 534 | 30 JUNE 2016

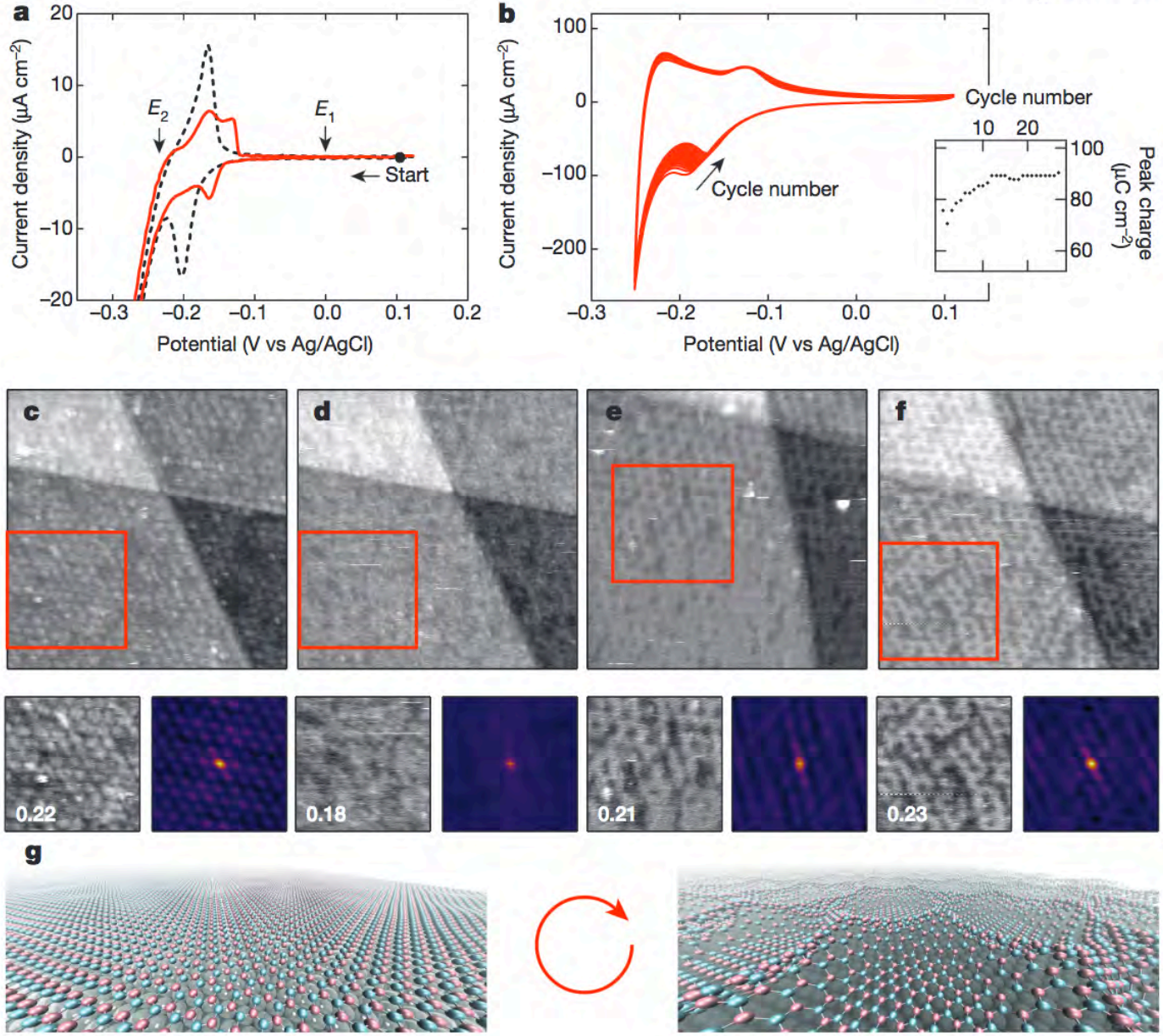
doi:10.1038/nature18275

Switching stiction and adhesion of a liquid on a solid

Stijn F. L. Mertens[1,2]*, Adrian Hemmi[3]*, Stefan Muff[3], Oliver Gröning[4], Steven De Feyter[1], Jürg Osterwalder[3] & Thomas Greber[3]

When a gecko moves on a ceiling it makes use of adhesion and stiction. Stiction—static friction—is experienced on microscopic and macroscopic scales and is related to adhesion and sliding friction[1]. Although important for most locomotive processes, the concepts of adhesion, stiction and sliding friction are often only empirically correlated. A more detailed understanding of these concepts will, for example, help to improve the design of increasingly smaller devices such as micro- and nanoelectromechanical switches[2]. Here we show how stiction and adhesion are related for a liquid drop on a hexagonal boron nitride monolayer on rhodium[3], by measuring dynamic contact angles in two distinct states of the solid–liquid interface: a corrugated state in the absence of hydrogen intercalation and an intercalation-induced flat state. Stiction and adhesion can be reversibly switched by applying different electrochemical potentials to the sample, causing atomic hydrogen to be intercalated or not. We ascribe the change in adhesion to a change in lateral electric field of in-plane two-nanometre dipole rings[4], because it cannot be explained by the change in surface roughness known from the Wenzel model[5]. Although the change in adhesion can be calculated for the system we study[6], it is not yet possible to determine the stiction at such a solid–liquid interface using *ab initio* methods. The inorganic hybrid of hexagonal boron nitride and rhodium is very stable and represents a new class of switchable surfaces with the potential for application in the study of adhesion, friction and lubrication.

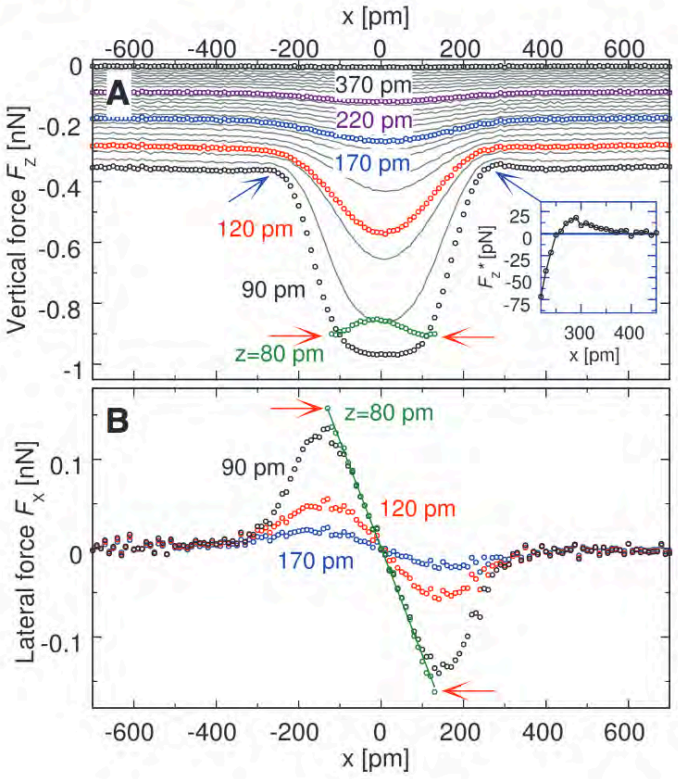
Figure 1 | Voltammetry and electrochemical scanning tunnelling microscopy.



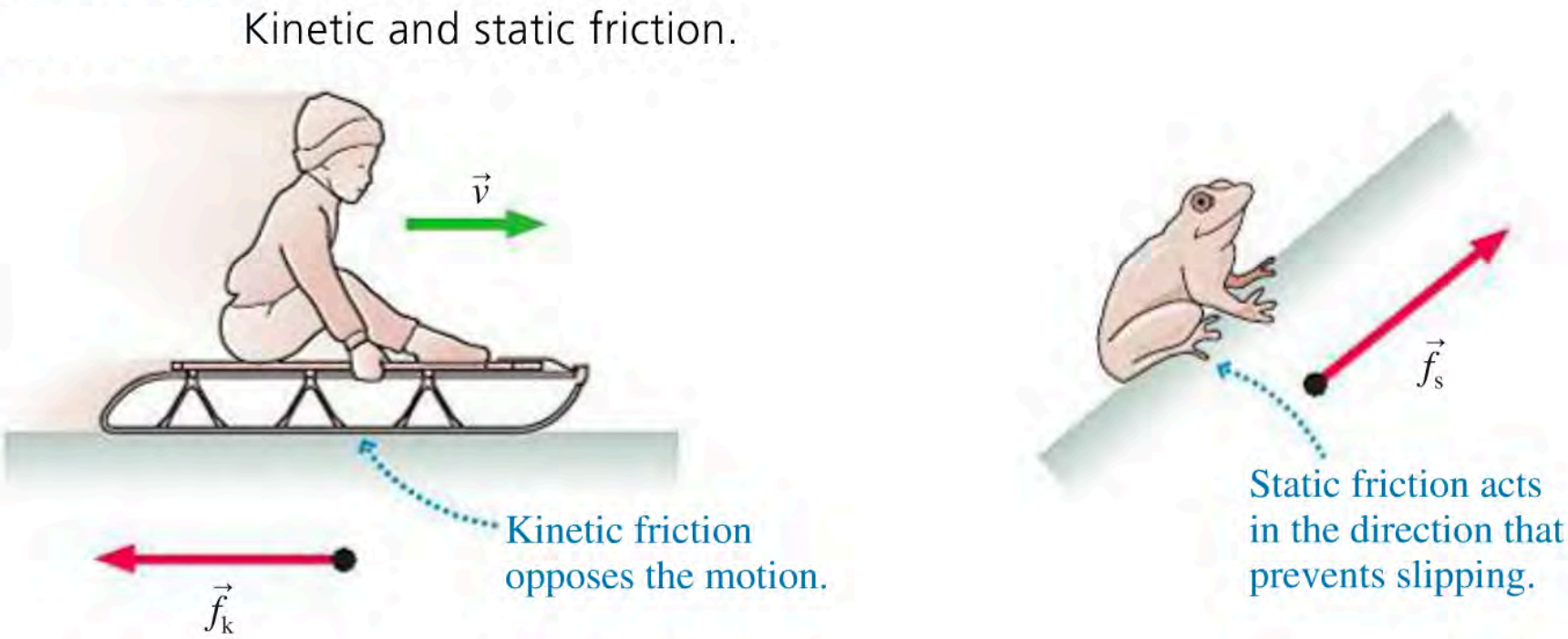
The Force Needed to Move an Atom on a Surface

Markus Ternes,[1]† Christopher P. Lutz,[1] Cyrus F. Hirjibehedin,[1]*
Franz J. Giessibl,[2] Andreas J. Heinrich[1]

Manipulation of individual atoms and molecules by scanning probe microscopy offers the ability of controlled assembly at the single-atom scale. However, the driving forces behind atomic manipulation have not yet been measured. We used an atomic force microscope to measure the vertical and lateral forces exerted on individual adsorbed atoms or molecules by the probe tip. We found that the force that it takes to move an atom depends strongly on the adsorbate and the surface. Our results indicate that for moving metal atoms on metal surfaces, the lateral force component plays the dominant role. Furthermore, measuring spatial maps of the forces during manipulation yielded the full potential energy landscape of the tip-sample interaction.



Friction: Static vs Kinetic



→ Key idea/distinction here is “static” versus “kinetic” friction

Knight (2013)

Friction: Static vs Kinetic

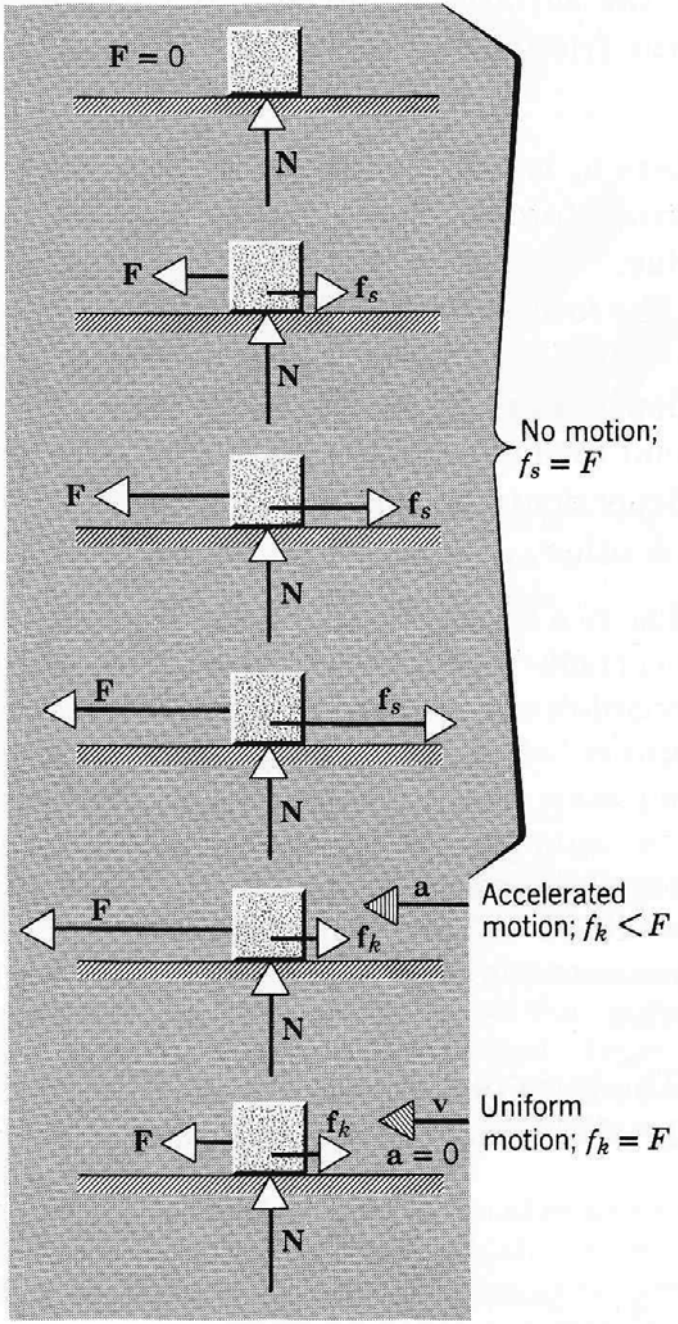
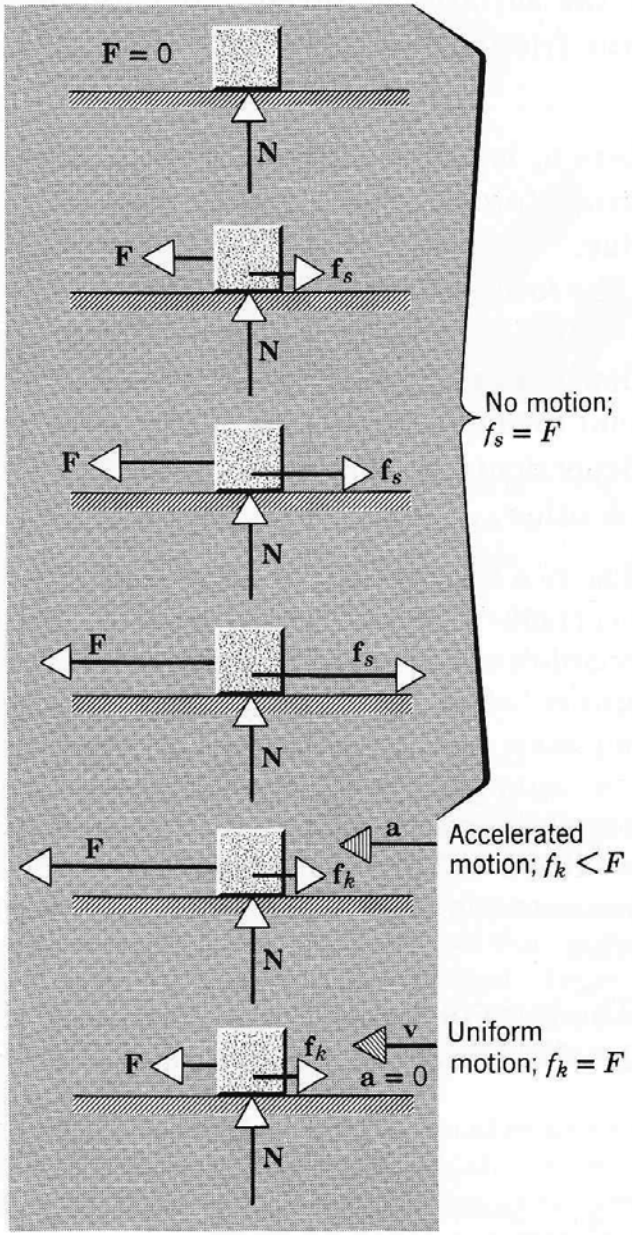
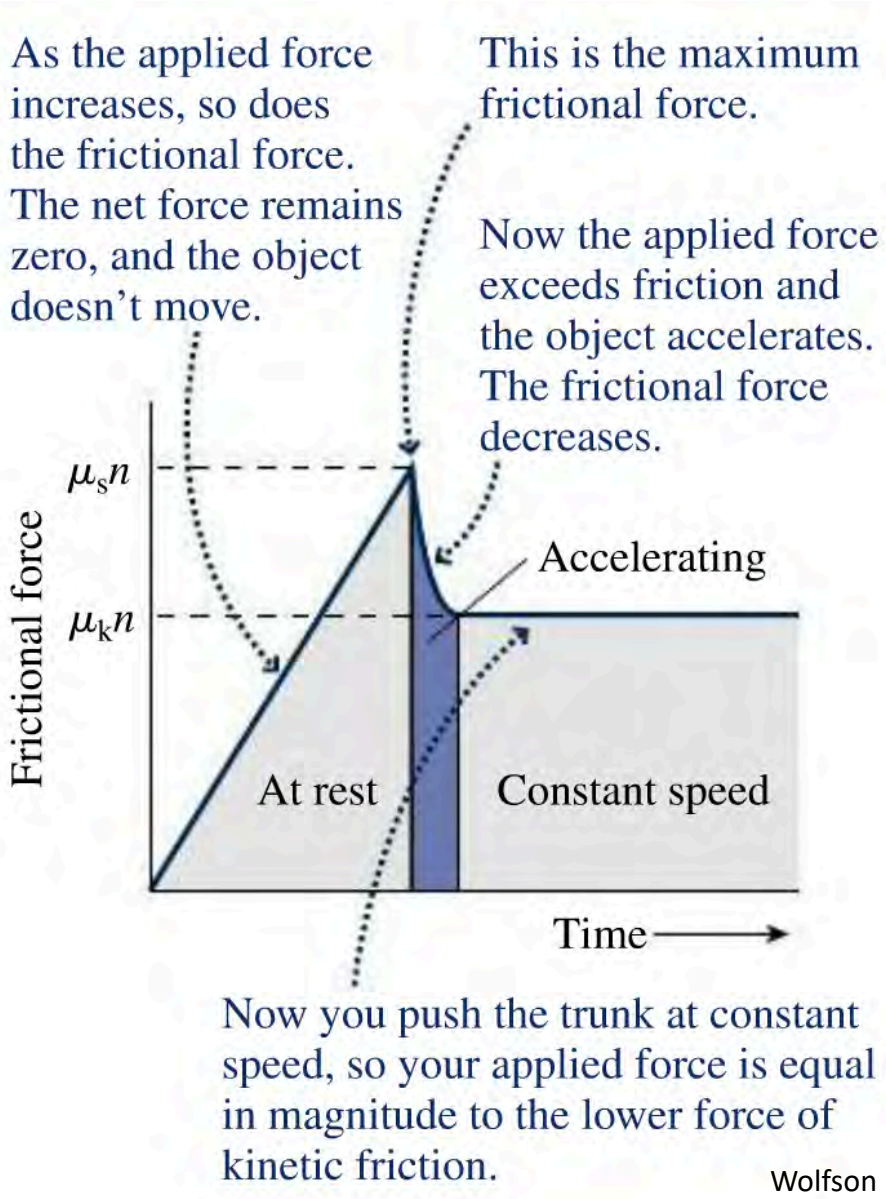


Fig. 6–1 A block being put into motion as applied force **F** overcomes frictional forces. In the first four drawings the applied force is gradually increased from zero to magnitude $\mu_s N$. No motion occurs until this point because the frictional force always just balances the applied force. The instant F becomes greater than $\mu_s N$, the block goes into motion, as is shown in the fifth drawing. In general, $\mu_k N < \mu_s N$; this leaves an unbalanced force to the left and the block accelerates. In the last drawing F has been reduced to equal $\mu_k N$. The net force is zero, and the block continues with constant velocity.

Resnick & Halliday (1966)

Friction: Static vs Kinetic





Wolfson

→ Two sides of the same coin here

Friction: Static vs Kinetic

If f_s represents the magnitude of the force of static friction, we can write

$$f_s \leq \mu_s N, \tag{6–1}$$

where μ_s is the coefficient of static friction and N is the magnitude of the normal force. The equality sign holds only when f_s has its maximum value.

The force of kinetic friction f_k between dry, unlubricated surfaces follows the same two laws as those of static friction. (1) It is approximately independent of the area of contact over wide limits and (2) it is proportional to the normal force. The force of kinetic friction is also reasonably independent of the relative speed with which the surfaces move over each other.

$$f_k = \mu_k N$$

Resnick & Halliday (1966)

"Laws of Friction"

The two laws of friction above were discovered experimentally by Leonardo da Vinci (1452–1519) and rediscovered, in 1699, by the French engineer G. Amontons. Leonardo's statement of the two laws was remarkable, coming as it did about two centuries before the concept of force was fully developed by Newton. Leonardo's formulation was: (1) "Friction made by the same weight will be of equal resistance at the beginning of the movement though the contact may be of different breadths or lengths" and (2) "Friction produces double the amount of effort if the weight be doubled." The French scientist, Charles A. Coulomb, (1736–1806) did many experiments on friction and pointed out the difference between static and kinetic friction.



Charles-Augustin de Coulomb (1736-1806)

(you'll see this guy again downstream re another very important inverse-square law in physics re "action-at-a-distance")

$$F = k_e \frac{q_1 q_2}{r^2}$$

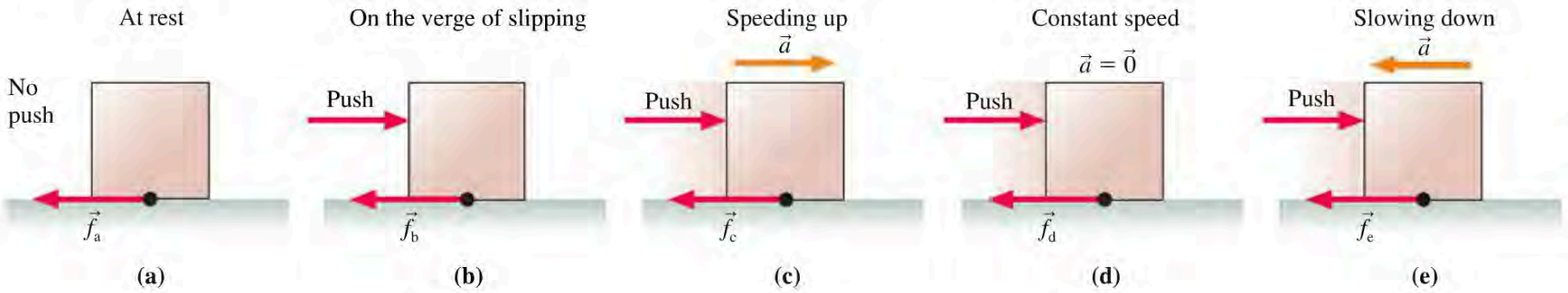
Resnick & Halliday (1966)



June 30, 2016 issue of Nature

Ex.

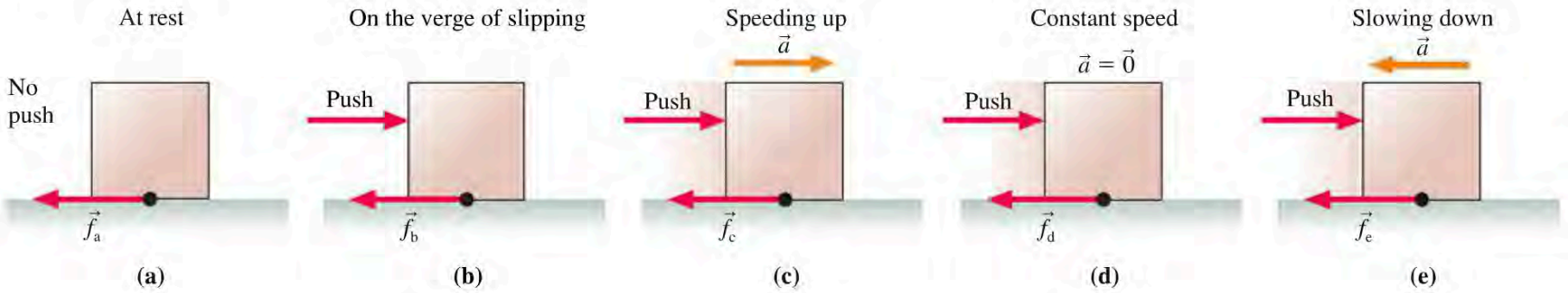
STOP TO THINK 6.3 Rank in order, from largest to smallest, the sizes of the friction forces $\vec{f}_a$ to $\vec{f}_e$ in these 5 different situations. The box and the floor are made of the same materials in all situations.



Knight (2013)

Ex. (SOL)

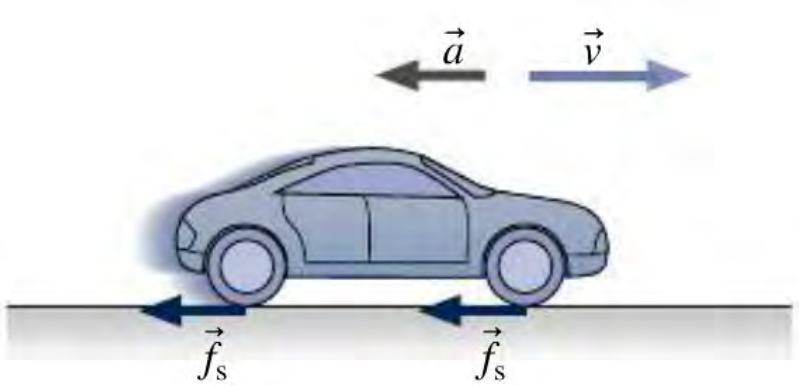
STOP TO THINK 6.3 Rank in order, from largest to smallest, the sizes of the friction forces $\vec{f}_a$ to $\vec{f}_e$ in these 5 different situations. The box and the floor are made of the same materials in all situations.

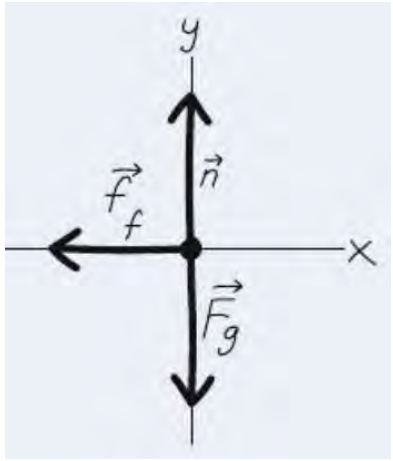


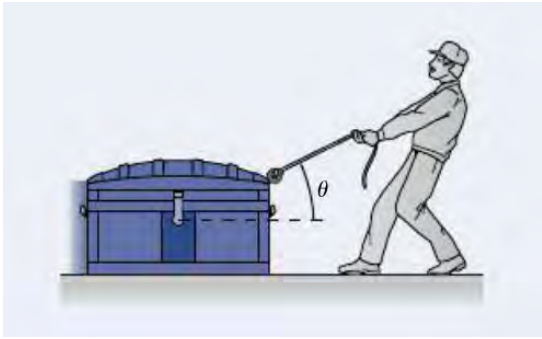
$$f_b > f_c = f_d = f_e > f_a$$

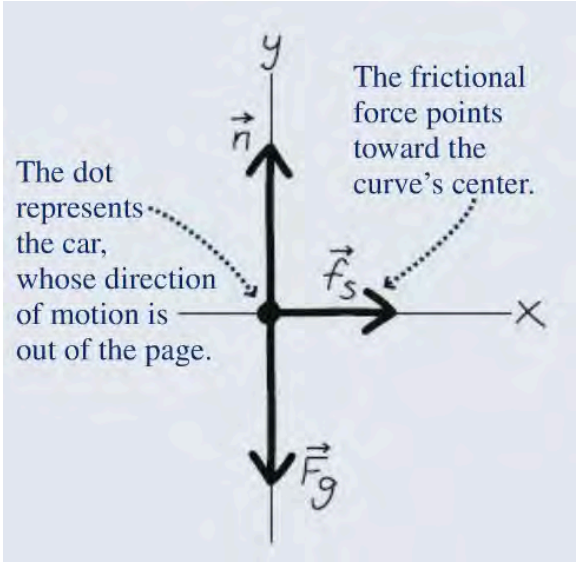
Knight (2013)

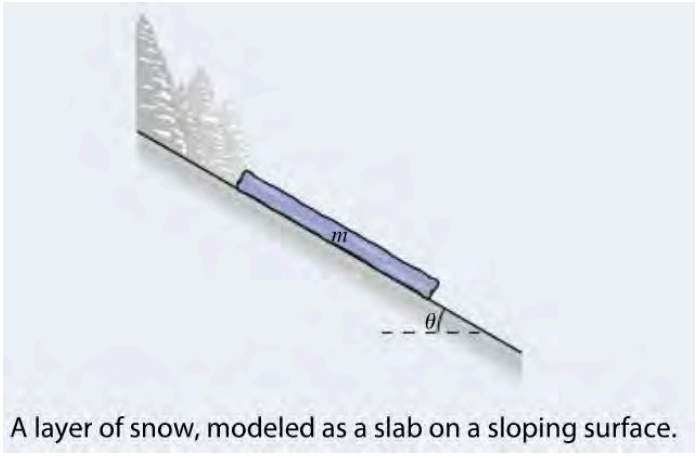
Problem Solving (re friction)



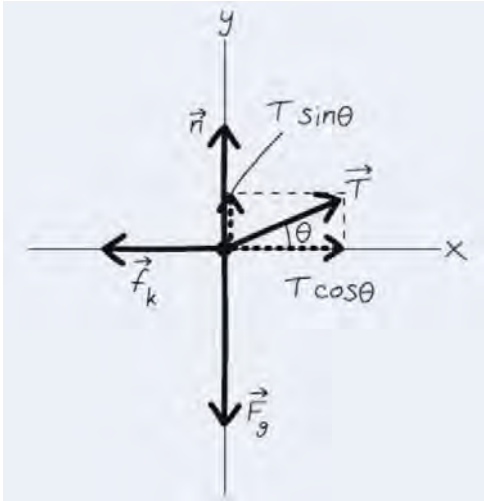








A layer of snow, modeled as a slab on a sloping surface.

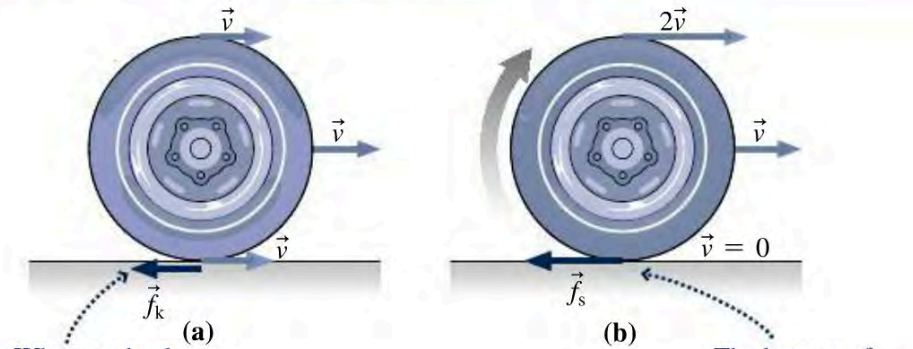


Friction: Static vs Kinetic vs "Rolling"

Note: For wheels, the notion of "rolling friction" here (as opposed to static friction) is a bit different re Kesten & Tauck (which is in ch.8!)

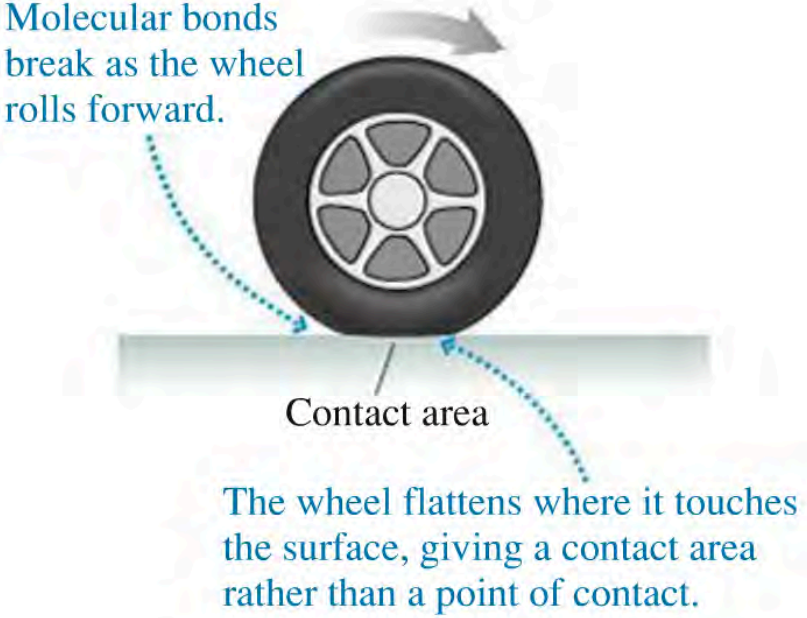
$$\text{Static: } \vec{f}_s \leq (\mu_s n, \text{ direction as necessary to prevent motion})$$
$$\text{Kinetic: } \vec{f}_k = (\mu_k n, \text{ direction opposite the motion})$$
$$\text{Rolling: } \vec{f}_r = (\mu_r n, \text{ direction opposite the motion})$$

APPLICATION **Antilock Brakes**



Wolfson

Rolling friction is due to the contact area between a wheel and the surface.



Knight (2013)

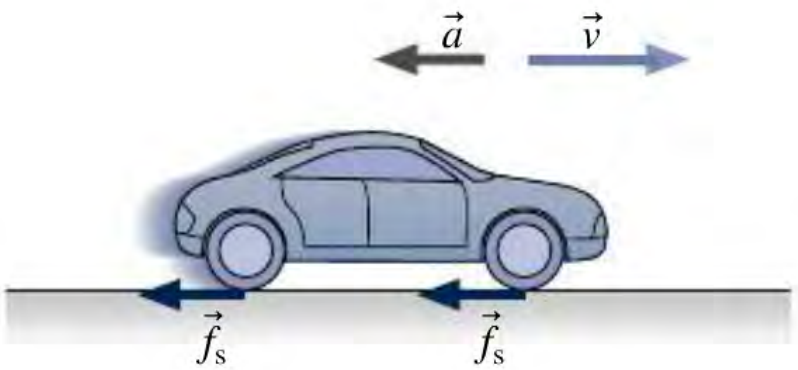
Friction: Static vs Kinetic vs "Rolling"

Coefficients of friction

Materials	Static μ_s	Kinetic μ_k	Rolling μ_r
Rubber on concrete	1.00	0.80	0.02
Steel on steel (dry)	0.80	0.60	0.002
Steel on steel (lubricated)	0.10	0.05	
Wood on wood	0.50	0.20	
Wood on snow	0.12	0.06	
Ice on ice	0.10	0.03	

Knight (2013)

→ Nonetheless, there are some key distinctions at play here!



The brakes affect only the wheels; it's friction between tires and road that stops the car. You know this if you've applied your brakes on an icy road!

Wolfson