Physics 141.
Lecture 8.

Outline.

- Course information:
  - Homework set 3
  - Lab 2
  - Exams
- Discussion of Chapter 5.
  - Important forces (e.g. friction, buoyant force).
- Start our discussion of Chapter 6: The energy principle.
  - Definition of the energy principle (aka the work-energy theorem).
  - Definition of Work.
  - Conservation of Energy.

Course Information.
Homework and Labs.

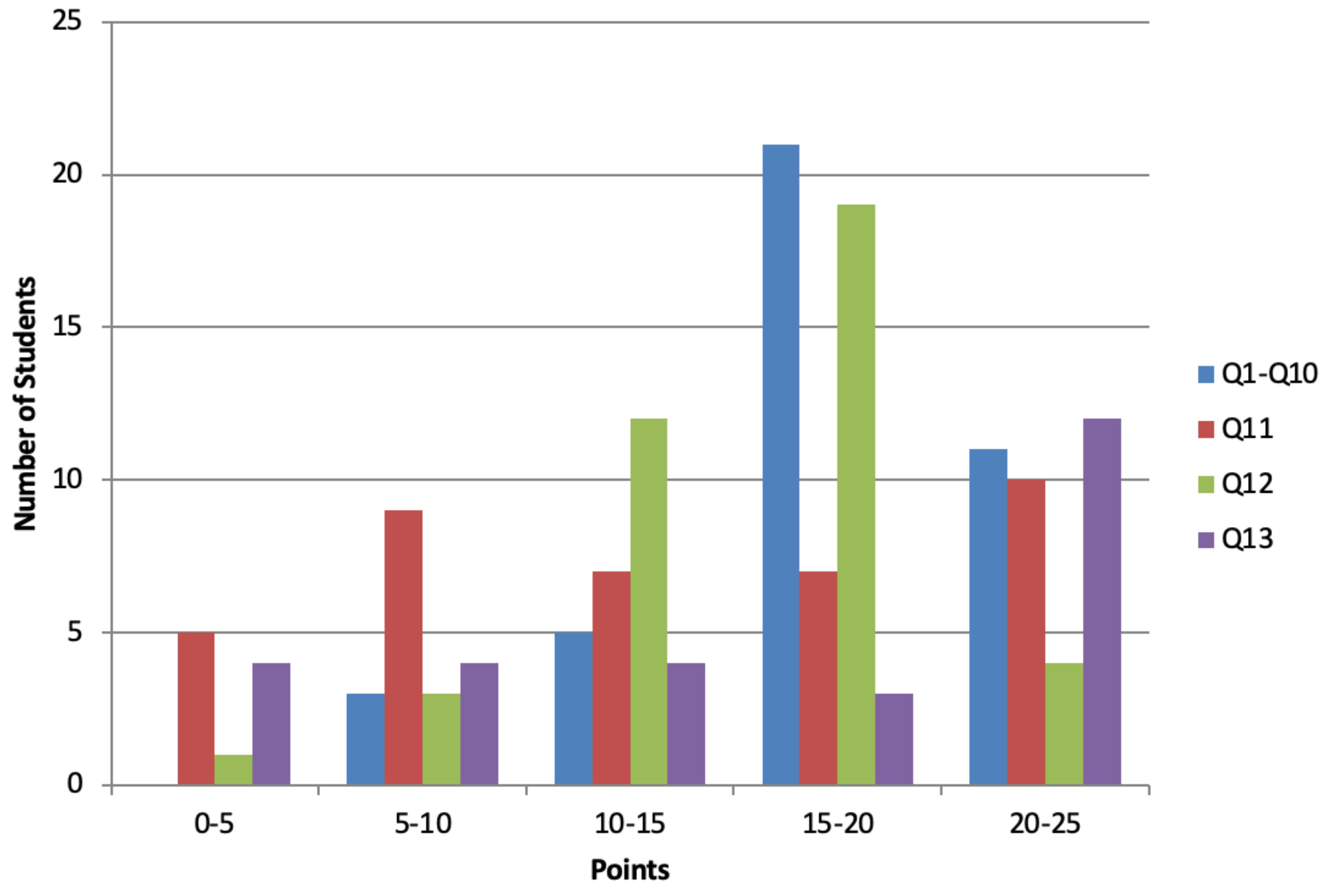
- Homework set # 3 is due on Friday morning 9/27 at 12 pm. **The written solutions must be put in the homework locker for the Physics 141 workshops (the lockers are located opposite of B&L 106).**

- Lab # 2 was carried out on Monday 9/23. The lab TIs will have lab office hours on Monday 9/30. This lab report will be due on Wednesday 10/2 at 12 pm (noon). Lab # 3 will take place on Monday October 7.

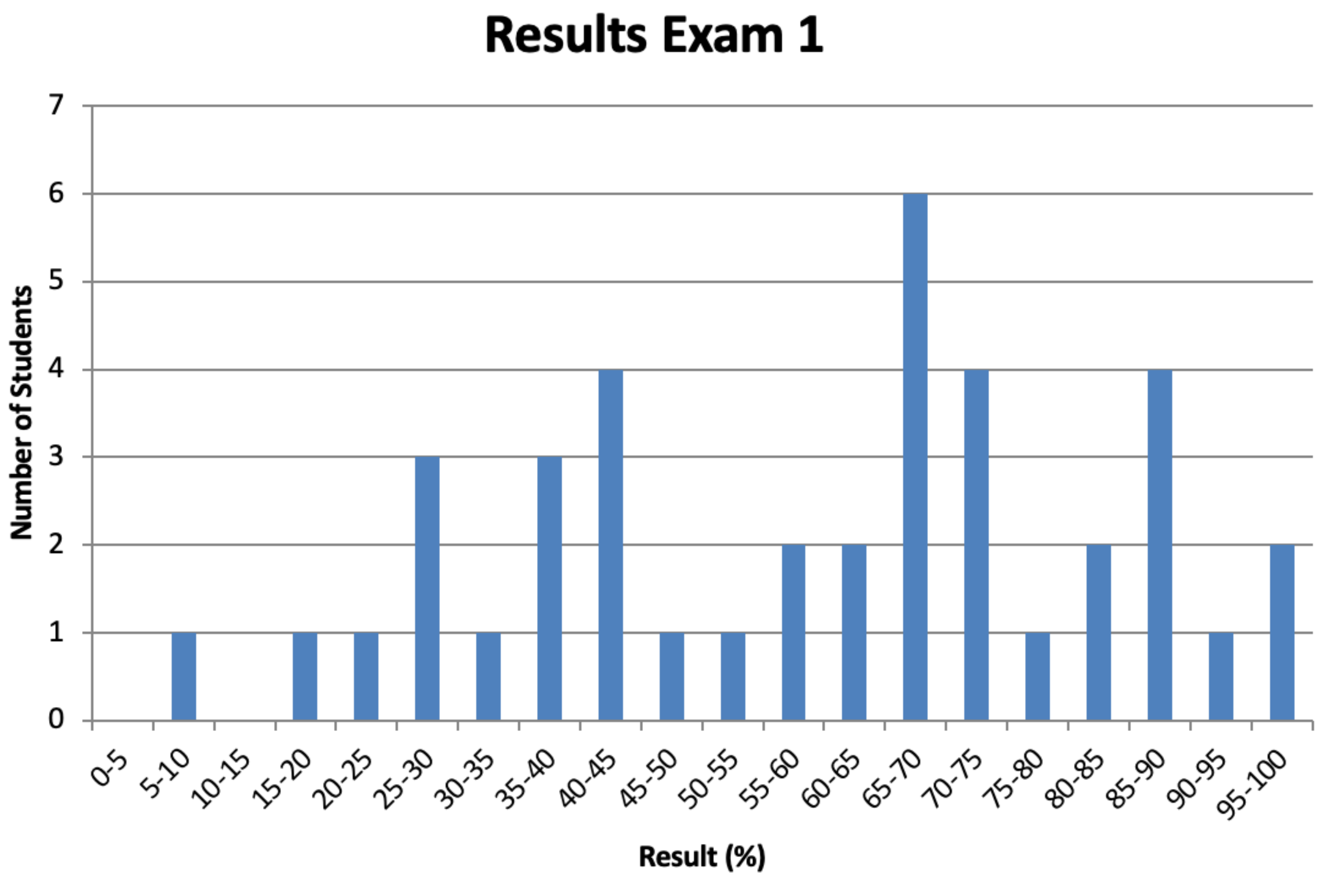
Course Information.
Exams.

- You will receive your solutions to Exam 1 during your recitation.
  - Compare the score you received on each question wit the score reported in the email you received on Monday.
- The solutions to Exam 1 are now available on our website.
  - Compare your solutions to the posted solutions.
- Exam 2 is scheduled in 3 1/2 weeks (Thursday October 17).
  - Exam 2 will cover chapters 4 to 7.
  - The format of Exam 2 will be similar to the format of Exam 1.
  - Make sure you learn from the mistakes you made on Exam 1.

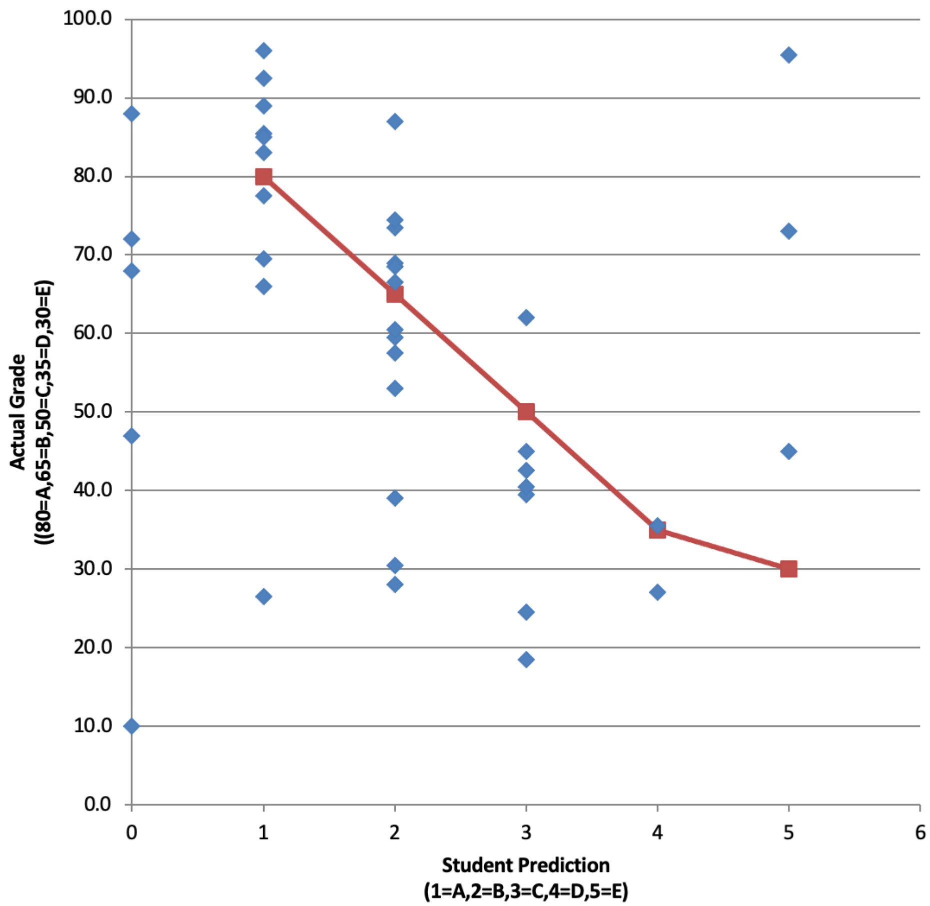
Results Exam # 1.
Point distributions.



Results Exam # 1.
Overall score distribution.

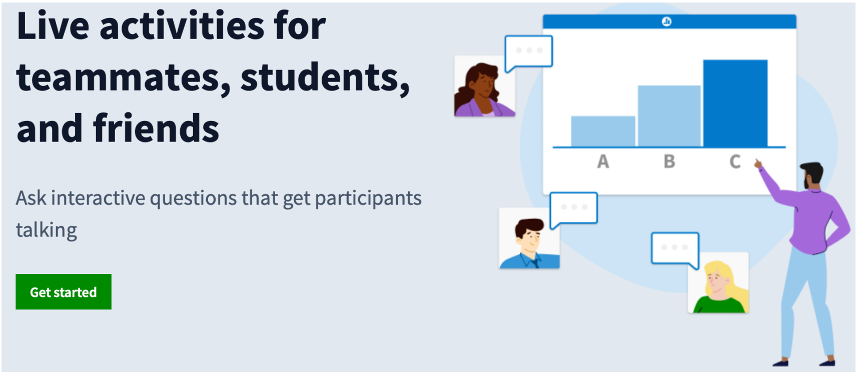


Results Exam # 1.
How well did you predict your result?



Quiz lecture 08.
PollEv.com/frankwolfs050

- The quiz today will have four questions: for two questions any answer is correct. Two additional questions are conceptual questions and are not part of your quiz grade.
- I will collect your answers electronically using the Poll Everywhere system.
- The answers for each question will be entered in sequence (first 60 s for question 1, followed by 60 s for question 2, etc.).



Force and motion.

- The momentum principle can be used in two different ways:
  - If you know the forces (F), you can use the momentum principle to predict the evolution of the motion $(dp = Fdt)$.
  - If you know the motion (dp), you can determine the properties of the unknown forces ($F = dp/dt$).
- The observation that an object does not carry out an acceleration in for example the vertical direction does not imply that there are no forces acting in the vertical direction. It only implies that the sum of all the forces in this direction is zero. Such observations may lead to the identification of previously unknown forces (such as the normal force N).

Force and motion.

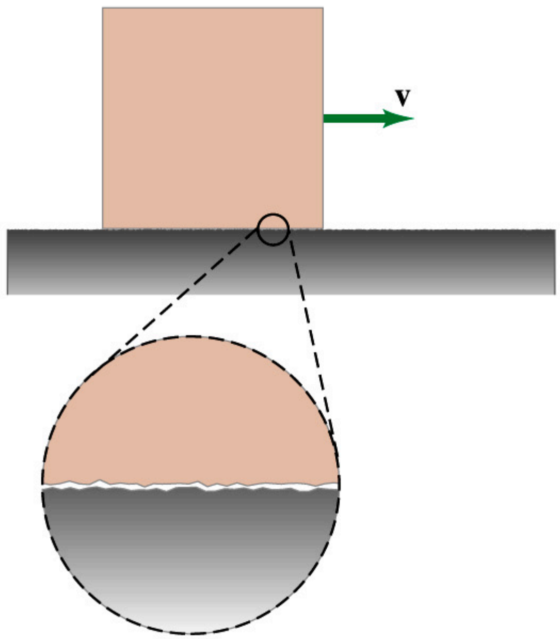
- Many other forces are frequently not included in our calculations since they may have no effect or only a very small effect on the motion.
- A good example is the force on an object due to the air molecules that surround it.
  - When the air molecules collide with this object, they change their direction and thus exert a force ($F = dp/dt$).
  - Since there are many air molecules, the force exerted by these molecules may be large (it will in general be directed in a direction perpendicular to the surface, pointing inwards).
  - The force exerted by the air on a surface determines the air pressure P: $P = F/A$.
  - Since the forces on different parts of the object will point in different directions, the net force acting on the object will be zero (or close to zero). But ……. air density variations may lead to a non-zero net force.

Force and motion.

- The force exerted by each molecule depends on its velocity (and thus on the temperature).
- The force exerted on a surface area *A* depends on the force exerted by each molecule and on the total number of molecules.
- Since the density of air increases with decreasing altitude, there is going to be net upward force acting on each object immersed in the air (the density at the bottom of the object is slightly larger than the density at the top of the object).
- The net force due to variations in density is the **Buoyant Force**.
- The effect of density variations is more apparent in liquids, since the density of liquids is much higher than the density of air.

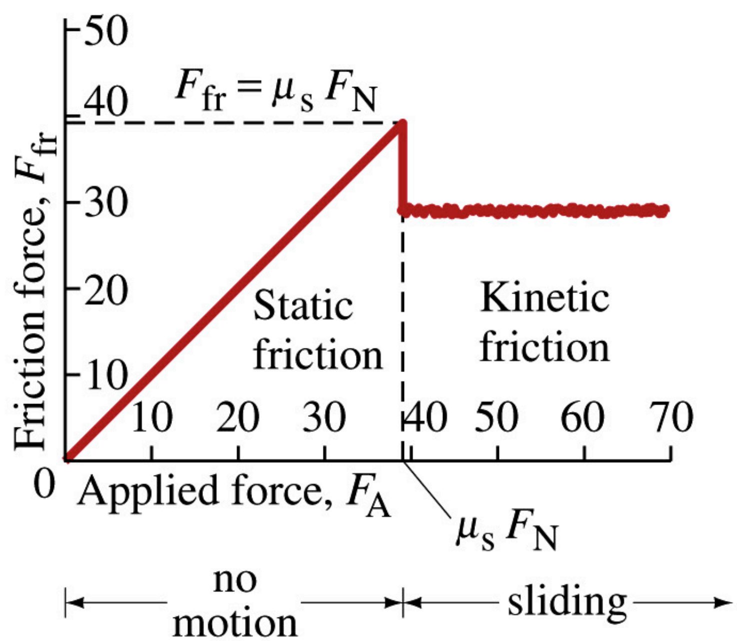
The friction force.
The force that opposes motion.

- A block on a table may not start to move when we apply a small force to it.
- This means that there is no net force in the horizontal direction, and that the applied force is balanced by another force.
- This other force must change its magnitude and direction based on the direction and magnitude applied force.
- If the applied force is large enough, the block will start to move and accelerate.



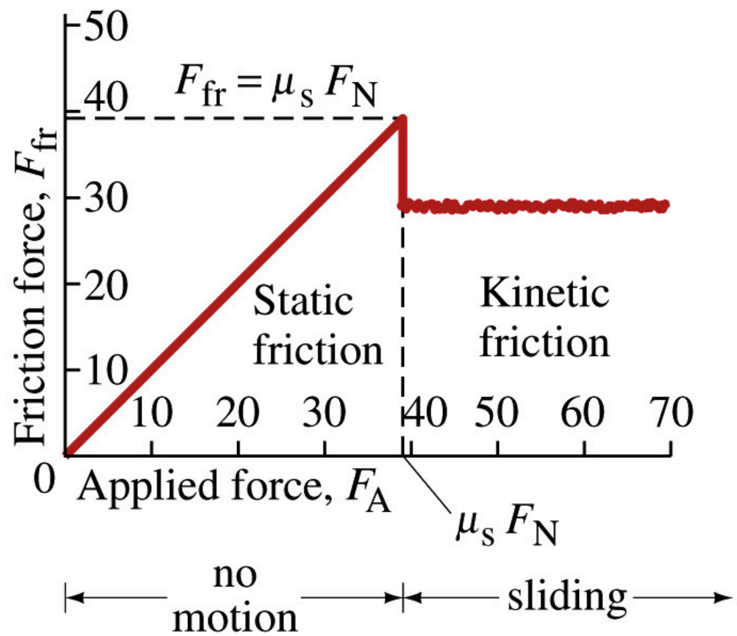
The friction force.
The force that opposes motion.

- Based on these observations we can conclude :
  - There are two different friction forces: the static friction force (no motion) and the kinetic friction force (motion).
  - The static friction force increases with the applied force but has a maximum value.
  - The kinetic friction force is independent of the applied force and has a magnitude that is less than the maximum static friction force.



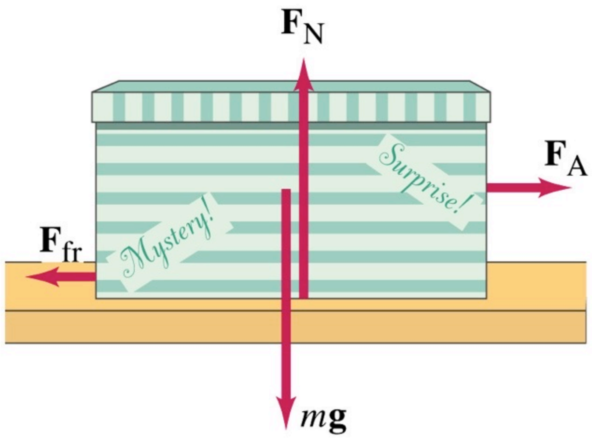
Friction and braking

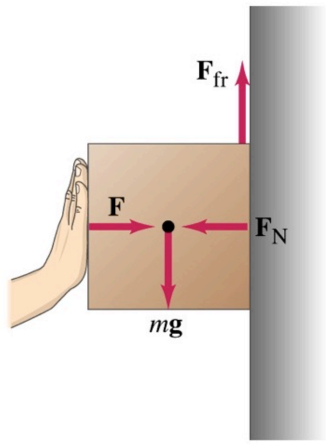
- Consider how you stop in your car:
  - The contact force between the tires and the road is the static friction force (for most normal drivers). It is this force that provides the acceleration required to reduce the speed of your car.
  - The maximum static friction force is larger than the kinetic friction force. As a result, you are **much** more effective stopping your car when you can use static friction instead of kinetic friction (e.g. when your wheels lock up).



Friction and normal forces.

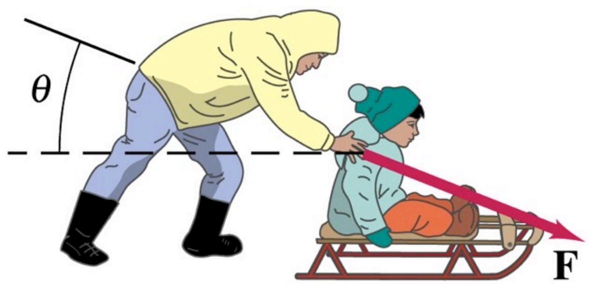
- The maximum static friction force and the kinetic friction force are proportional to the normal force.
- Changes in the normal force will thus result in changes in the friction forces.
- **NOTES:**
  - The normal force will be always perpendicular to the surface.
  - The friction force will be always opposite to the direction of (potential) motion.
  - Static friction: $F_{fr} \leq \mu_s N$
  - Kinetic friction: $F_{fr} = \mu_k$

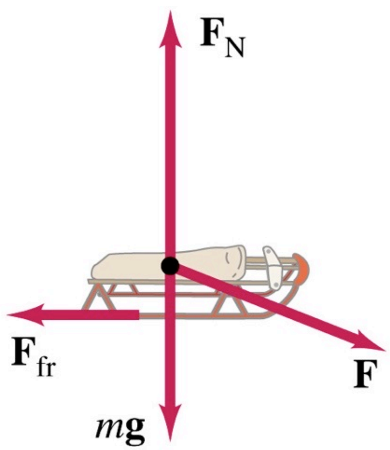




Pushing or pulling: a big difference.

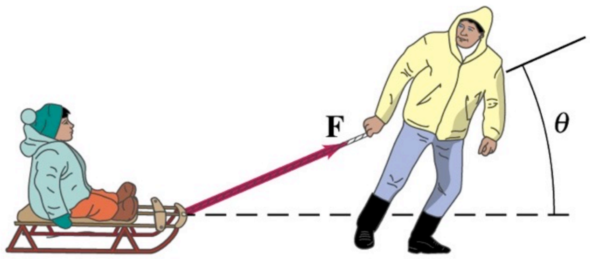
More friction

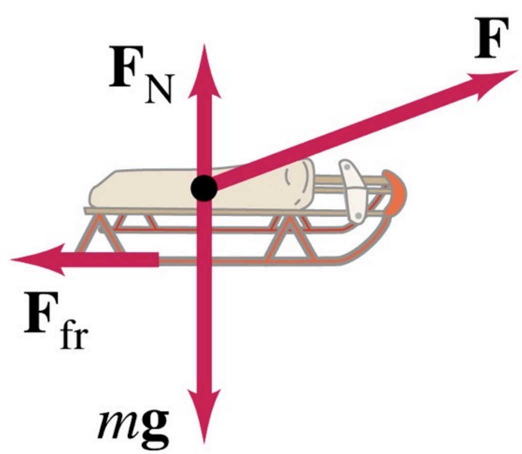




$$F_N = mg + F\sin\theta$$

Less friction



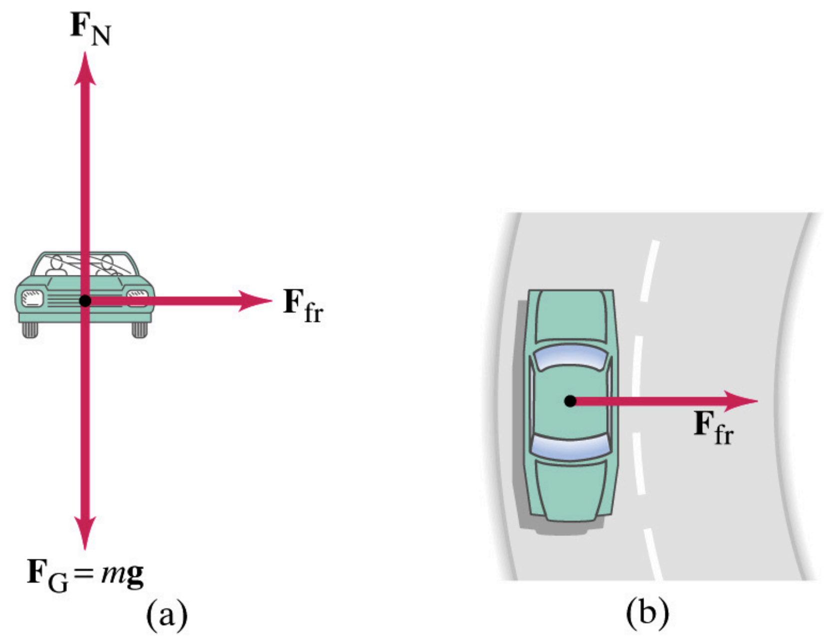


$$F_N = mg - F\sin\theta$$

Using friction: making a turn.

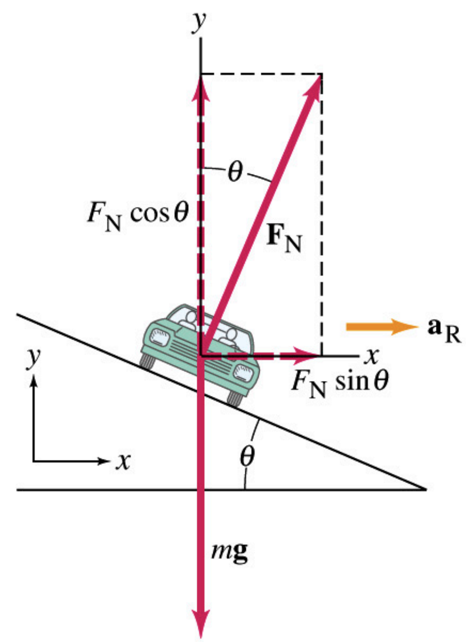
- When you drive your car around a corner you carry out circular motion.
- In order to be able to carry out this type of motion, there must be a force present that provides the required acceleration towards the center of the circle.
- This required force is provided by the friction force between the tires and the road.
- But remember ….. The friction force has a maximum value, and there is a maximum speed with which you can make the turn.

Required force = Mv^2/r.
If v increases, the friction force must increase and/or the radius must increase.



Using friction: making a turn.

- Unless a friction force is present you can not turn a corner …… unless the curve is banked.
- A curve that is banked changes the direction of the normal force.
- The normal force, which is perpendicular to the surface of the road, can provide the force required for circular motion.
- In this way, you can round the curve even when there is no friction ……. but only if you drive with exactly the right speed (the posted speed).



Using friction: making a turn. The new Tappan Zee bridge.

- The old bridge did not have banked curves on either end.
- The old bridge had double the accident rate compared to any other stretch of the New York State Thruway.
- The new bridge has banked curves on the last ½ mile on either side of the bridge.

New Tappan Zee Bridge — a span you can bank on

PETER D. KRAMER
WESTCHESTER JOURNAL NEWS

PETER CARR/THE JOURNAL NEWS

Workers stand on a concrete support pier as they wait for a girder assembly to be set in place for the new Tappan Zee Bridge in June.

Here's a new angle on the new Tappan Zee Bridge: It'll have an angle to it.

Eagle-eyed drivers on the Thruway might have noticed that some of the 400-foot-long, sky-blue girders that have begun to give the bridge shape are set at an angle to the river.

The girders, on which the twin roadbed will eventually be set, rest on individual support blocks atop the massive piers. At both ends of the new bridge — in Tarrytown and South Nyack, where the road is curved — those support blocks are at graduated heights, giving the bridge a bank like a race track.

NASCAR track designers like to say "banking equals speed." They employ high banks — different at each track, but a record-setting 33 degrees at Talladega Superspeedway — to rocket cars out of the curves and down the straightaways. But banking also gives drivers extra traction and prevents cars from slipping laterally out of a curve.

We asked David Capobianco, project delivery manager for the New NY Bridge (the new Tappan Zee's working title), to explain the banking, which bridge designers have dubbed "superelevation."

"The superelevation of the road deck on the new bridge is one of the many safety enhancements being incorporated into its design, including wider travel lanes, a gentler slope over the main span, improved drainage as well as breakdown and emergency access lanes," Capobianco said.

The New New York Bridge will be banked. How much of a tilt are we talking about?

The "superelevation" is generally between 4½ to 5 feet.

What is the purpose of the tilt?

The "tilt" is termed superelevation which is the banking of the roadway (or bridge deck) cross slope to counter the centrifugal forces of a vehicle traveling around a curve. It serves to improve safety by relying less on friction to keep vehicles from skidding or losing control around curves (especially in rain or snow/ice conditions) and also minimizes the likelihood of truck rollovers.

What is the degree of the tilt?

The "degree of tilt" is termed the rate of superelevation which is 5.8 percent. In other words, within a standard 12-foot travel lane, the "tilt" would be 12 x 0.058 = 0.7 feet or about 8¼ inches. (This would be the difference in elevation between the lane stripes.)

How far on the bridge will that tilt last?

There are curves for about ½ mile on each end of the bridge as it approaches the landings and these are the areas of the bridges that include superelevation.

Does the current Tappan Zee Bridge have a similar tilt?

No, the existing bridge does not have superelevation in the curved sections and that is one of the reasons the existing span has double the average accident rate compared to any other stretch of the 570-mile New York State Thruway.

How noticeable will the tilt be when driving the new bridge? Will we be able to tell?

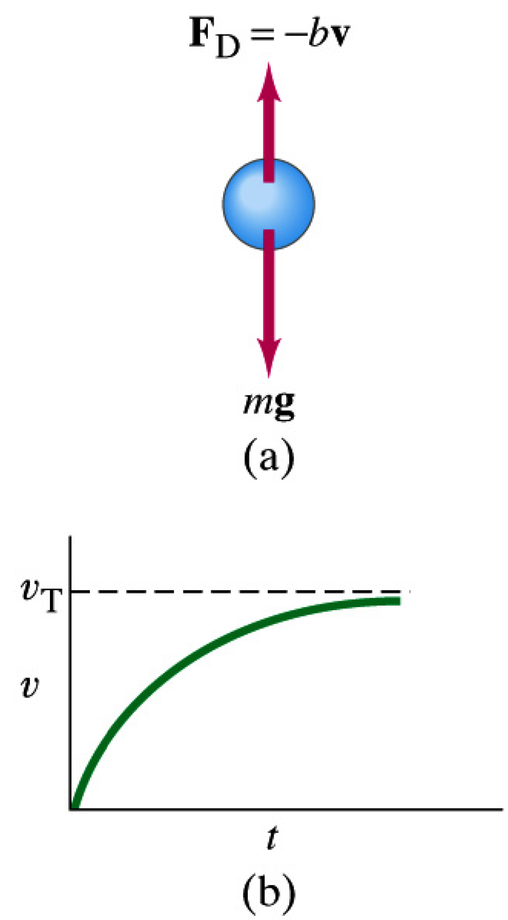
The superelevation should not be noticeable when traversing the bridge. Gentle banking is utilized on almost all highways so you have been experiencing this already in your everyday travels. It would be most apparent in a stopped condition.

NASCAR uses a bank to help drivers maintain high speeds and propel cars down the straightaway. Any concerns about NASCAR wannabes getting inspired by the bank?

No, the degree of banking or superelevation for race tracks is significantly higher than what is used on highways.

Air “friction” or drag

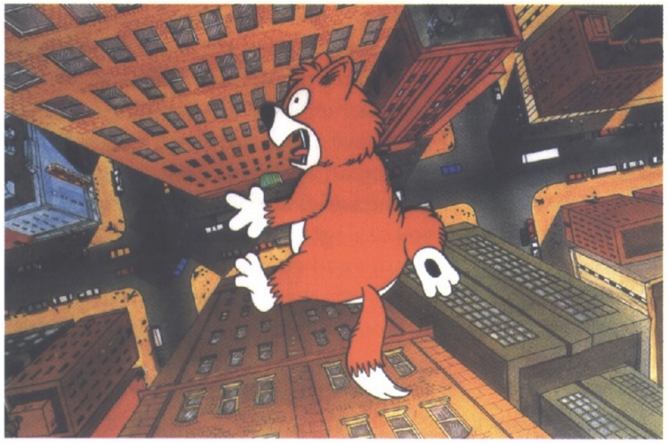
- Objects that move through the air also experience a “friction” type force.
- The drag force has the following properties:
  - It is proportional to the cross-sectional area of the object.
  - It is proportional to the velocity of the object.
  - It is directed in a direction opposite to the direction of motion.
- The drag force is responsible for the object reaching a terminal velocity (when the drag force balances the gravitational force).



Terminal Velocity:
This is not the proper definition!

Terminal air “friction” or drag.

- The science of falling cats is called feline pesematology.
- This area of science uses the data from falling cats in Manhattan to study the correlation between injuries and height.
- The data show that the survival rate is doubling as the height increases (effects of terminal velocity). E.g. only 5% of the cats who fell seven to thirty-two stories died, while 10% of the cats died who fell from two to six stories.



End of the discussion of Chapter 5.

- After our intermission we will start with Chapter 6 where conservation of energy is introduced.

2 Minute 54 Second Intermission

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 2 minute 54 second intermission.

- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Go asleep, as long as you wake up in 2 minutes and 54 seconds.

Start of Chapter 6.

- In Chapter 6 we will discuss one of the most important conservation laws in physics: **conservation of energy**.

- Applying conservation of energy in general will simplify the way in which we can make predictions about the evolution or the dynamics of a system of particles.

- In many cases, the evolution can be determined by either using the equations of motion or by applying conservation of energy. The greatest difficulty is often to determine which approach to apply.

The energy principle.

- The energy principle states that the change in energy of a system (ΔE_{system}) is equal to the work done by the surroundings (W_{surr}) and the energy flow (Q) between the system and surroundings due to a difference in temperature:

$$\Delta E_{system} = W_{surr} + Q$$

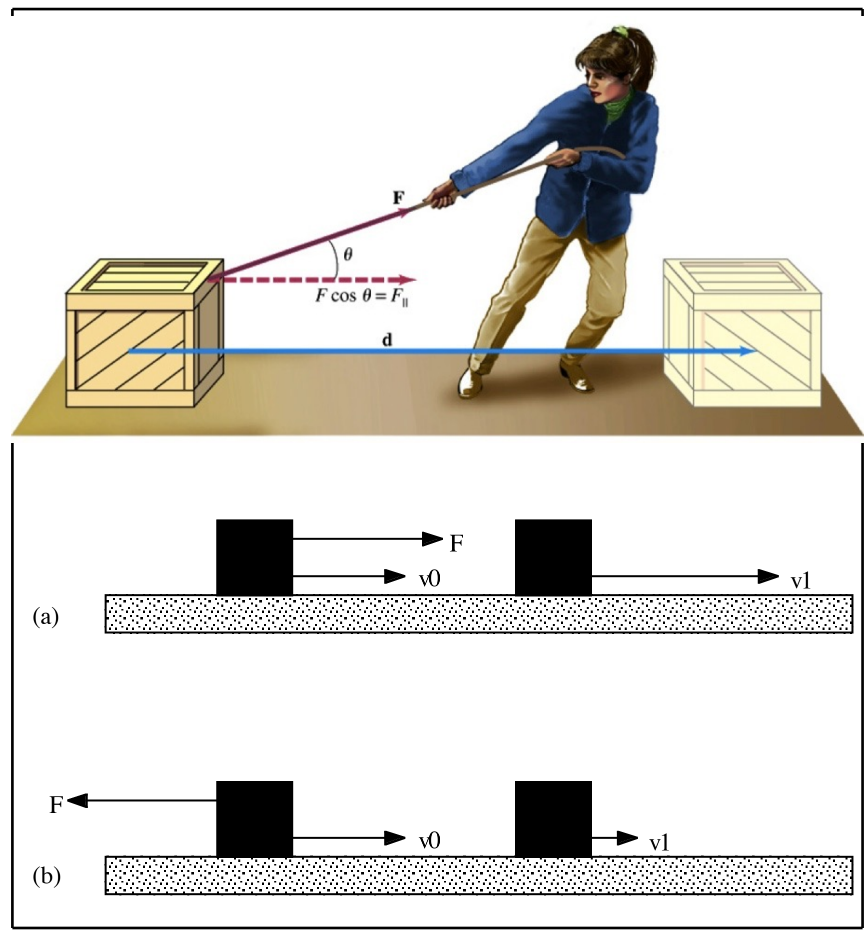
- The energy principle is a fundamental principle:
  - It applies to every possible system (from very small sizes to very large sizes).
  - It holds for any kind of interaction.
  - It relates an effect (the change in energy) to a cause (an interaction between a system and its surroundings).
- The validity of the principle has been verified in many different experiments.

But what is work and what is energy?

- When a force F is applied to an object, it may produce a displacement d.
- The work W done by the force F is defined as

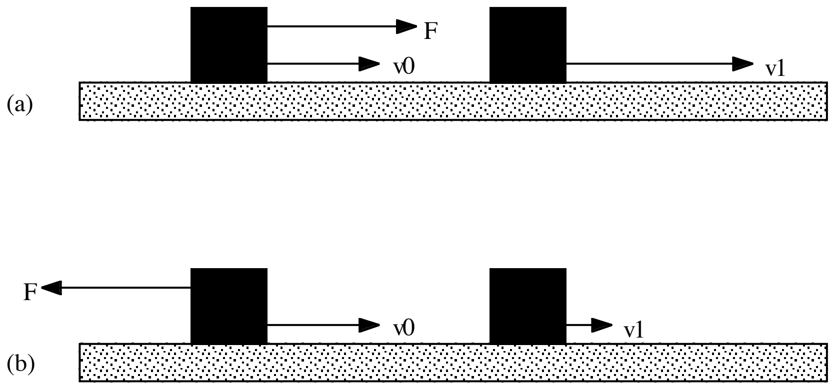
$$W = \vec{F} \cdot \vec{d} = Fd\cos(\theta)$$

  where θ is the angle between the force F and the displacement d.
- The work done by the force F is zero if:
  - $d = 0$ m (no displacement).
  - $\theta = 90°$ (force perpendicular to the displacement).



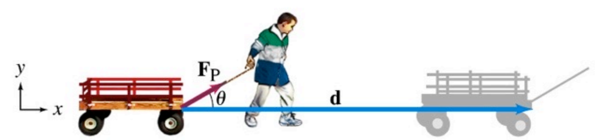
Work.
Positive, zero, or negative.

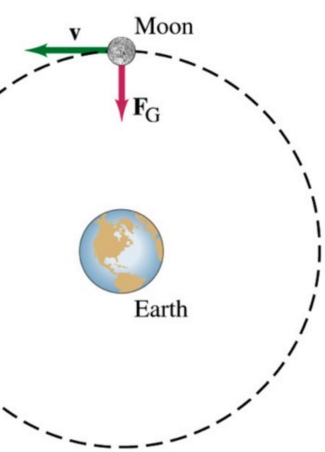
- Work done by a force can be positive, zero, or negative, depending on the angle θ :
  - When $0° \leq \theta < 90°$ (scalar product between F and d is larger than 0) the speed of the object will increase.
  - When $\theta = 90°$ (scalar product between F and d is 0) the speed of the object will not change.
  - When $90° < \theta \leq 180°$ (scalar product between F and d is smaller than 0) the speed of the object will decrease.



Work: units.

- The unit of work is the Joule (abbreviated J).
- Per definition, 1 J = 1 Nm = 1 kg m^2/s^2.
- There are many important examples of forces that do not do any work. For example, the gravitational force between the earth and the moon does not do any work! Note: in this case, the speed of the moon does not change.

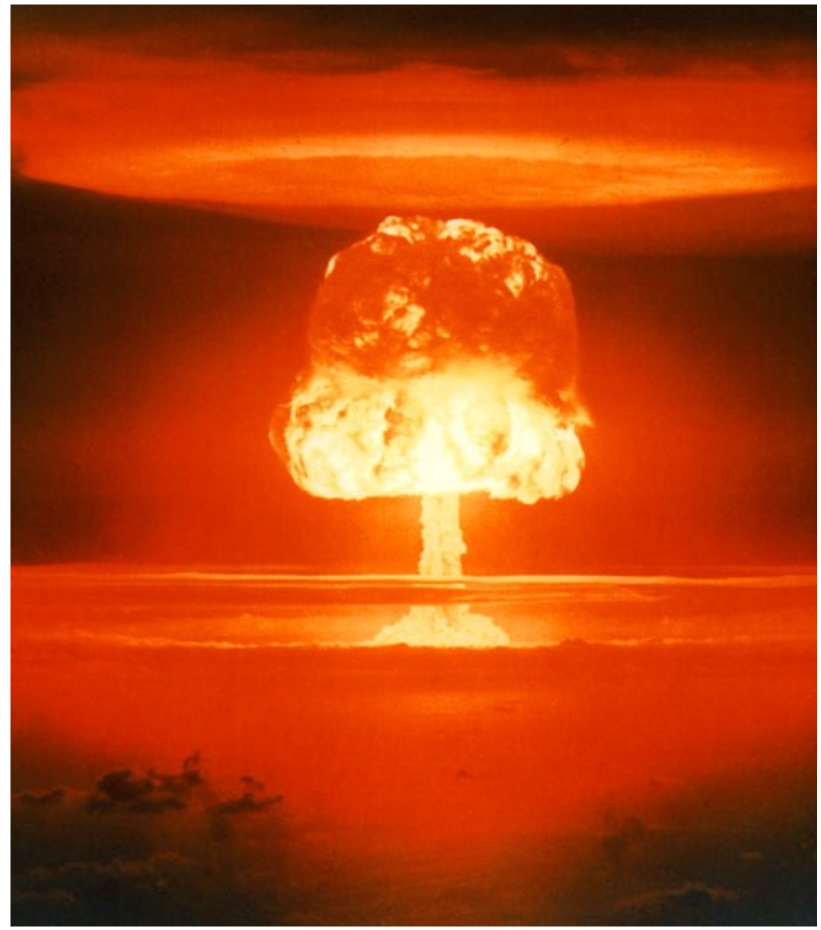




Power.

- In many cases, the work done by a tool is less important than the the rate with which the work can be done.

- For example, explosive devices get their properties from being able to do a lot of work over a very short period in time. The same amount of work done over a longer period of time might not lead to destruction.



Power: units.

- Power of defined as work per unit time:

$$P = \frac{dW}{dt}$$

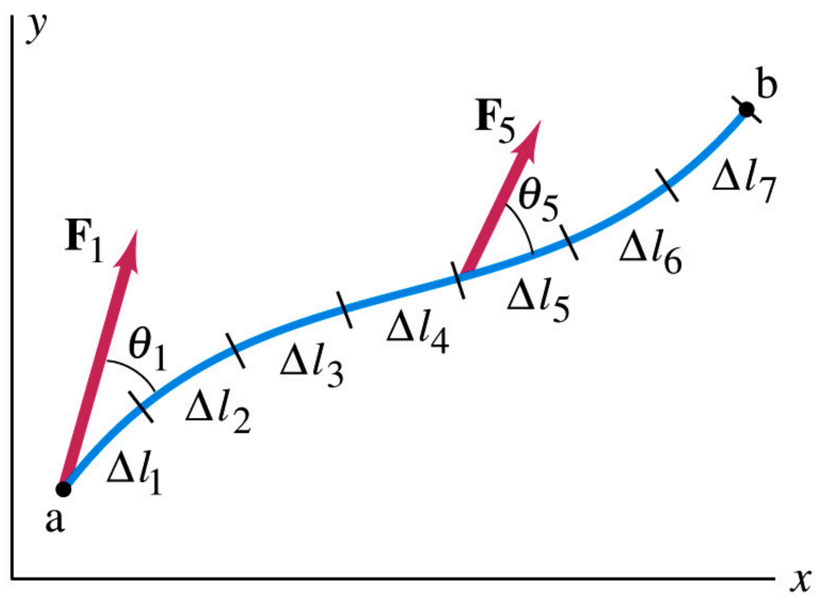
- The unit of power is the Watt, abbreviated by a W.
- Per definition:

$$1 \text{ W} = 1 \text{ J/s} = 1 \text{ kg m}^2/\text{s}^3$$

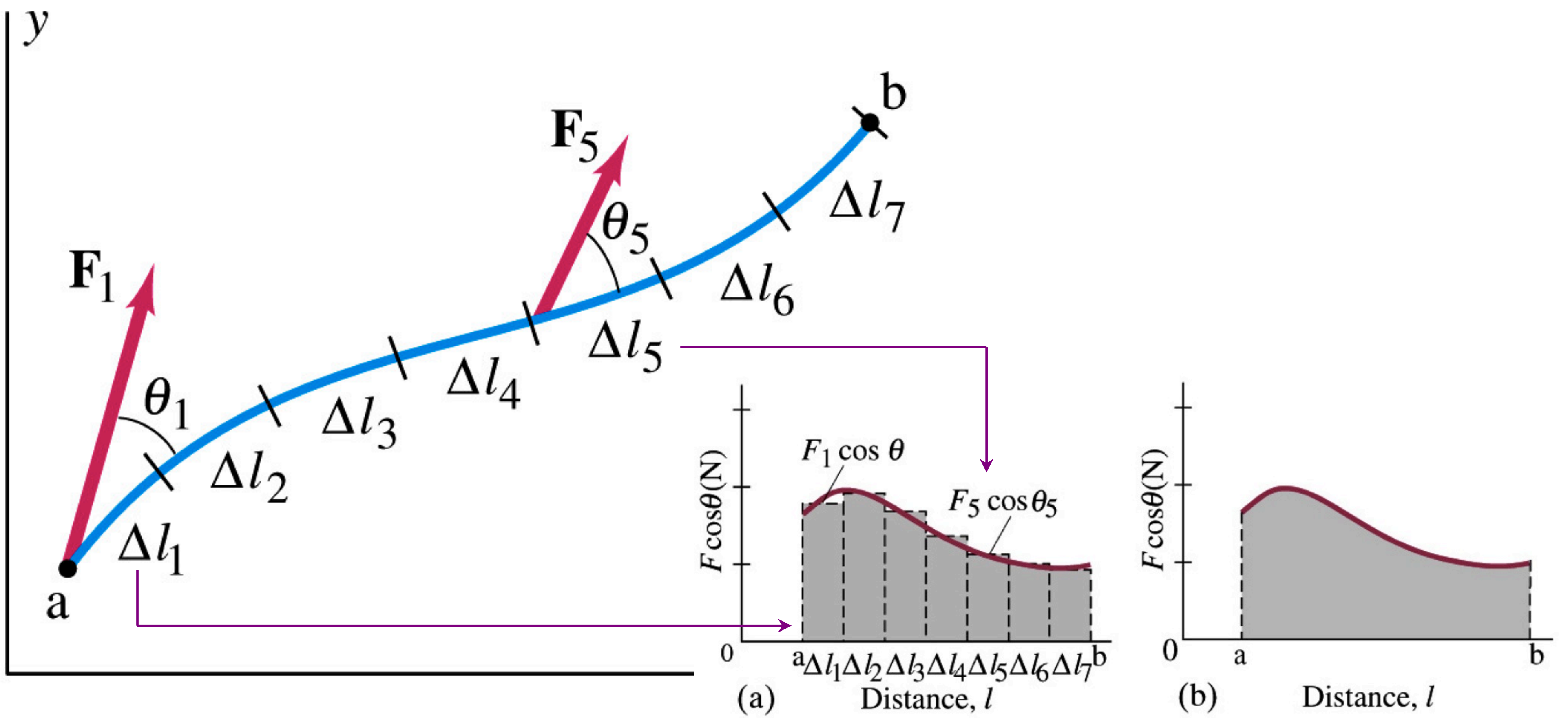
- The power you consume at home is often expressed in terms of kWh, which is the use of 1 kW of power for 1 hour.

Work done by a varying force.

- In most realistic cases, we need to consider the work done when the force is varying (both in magnitude and direction) as function of time and/or position.
- In this case, we can still use the same approach as we just discussed by breaking up the motion into small intervals such that the path is linear and the force is constant during the intervals considered.



Work done by a varying force.



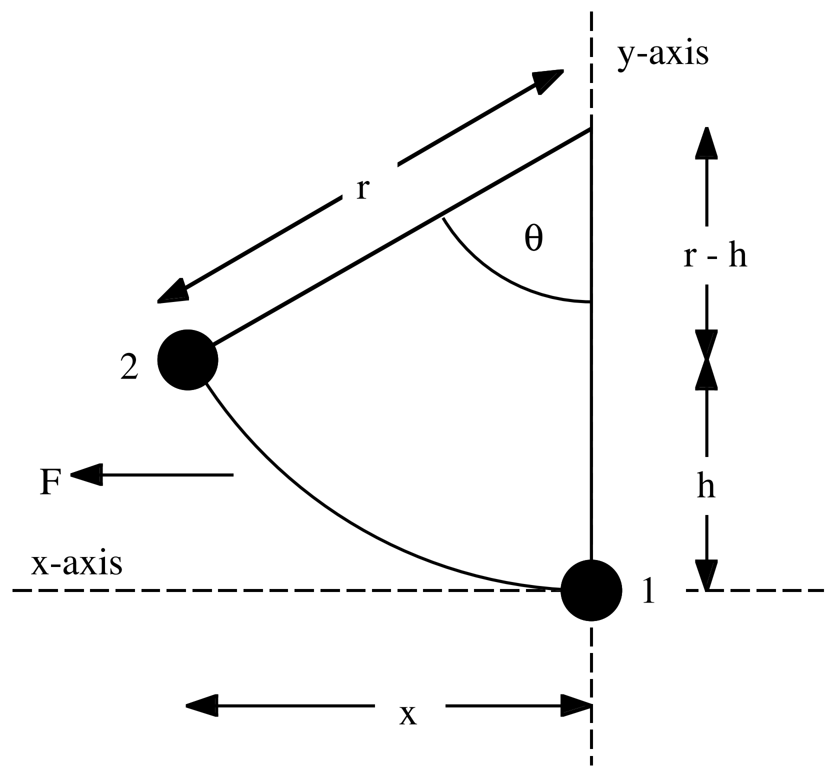
Calculating work.
Do less work by thinking before starting!

- Consider the work done by all forces acting on the pendulum when it moves from position 1 to position 2.
- During this motion, the angle between the path and the net force changes. What am I to do?

$$W = \vec{F}_t \cdot \vec{d} = \left(\vec{F} + \vec{F}_g\right) \cdot \vec{d}$$

$$\vec{F} \cdot \vec{d} = Fx = F\sqrt{h(2r - h)}$$

$$\vec{F}_g \cdot \vec{d} = -F_g h = -mgh$$



Done for today!
Next lecture: more energy!