DAY 9

Summary of Primary Topics Covered

Friction

There are many different types of frictional forces. However, frictional forces can usually be identified by the fact that they involve motion, and they turn other forms of energy into heat.

Friction – Air Drag/Air Resistance

Air drag is the frictional force an object feels as it moves through air or another gas, as in the case of the drag force you feel when you pedal a bicycle fast. It can also be the force air exerts on something when the air itself is moving, as in the force a strong wind exerts on a building.

Air Drag depends on four factors:

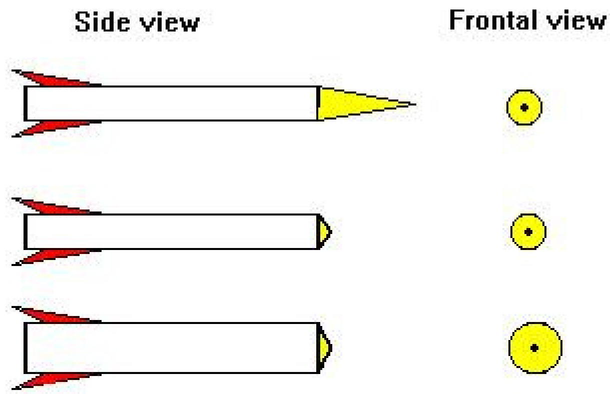
- The speed at which air is flowing past an object (v)
- The area the object has facing into the air flow (A)
- The shape of the object (how "aerodynamic it is – indicated by the drag coefficient C_d)
- The density of the air (ρ)

These all come together in the following equation for air drag force (D):

$$D = \frac{1}{2}\rho A C_d v^2$$

Drag coefficients (C_d) depend primarily on shape. A sphere has a C_d of roughly 0.5. Objects more aerodynamic than a sphere have $C_d < 0.5$. Objects less aerodynamic than a sphere have $C_d > 0.5$. C_d's for specific shapes usually have to be looked up from a table.

If all three rockets are moving to the right at the same speed, the one on top will experience the least air drag. The one on bottom will experience the most. The top rocket has the same frontal area as the middle rocket but has a more aerodynamic shape (lower C_d). The bottom rocket will have the same C_d as the middle rocket (because they both have the same shape) but it has a larger frontal area.



A table of drag coefficients has been added to the class web page.

Freely falling objects that move through air will eventually not be freely falling because the faster they move the more significant the drag force on them becomes. Eventually, if an object falls for long enough, it will get moving so fast that the drag force on it equals the downward pull of gravity. At this point the net force on the falling object is zero, the object stops accelerating, and it moves downward with a constant speed known as *terminal velocity*.

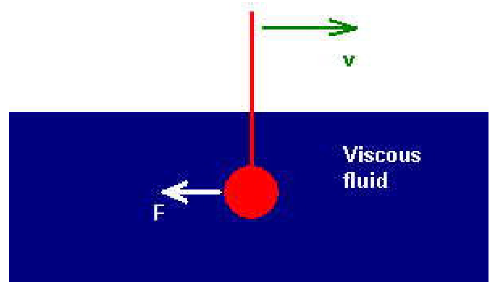
Friction in Viscous Fluids

Viscous fluid friction occurs when objects are moving fairly slowly through a *viscous* fluid. Viscosity refers to a fluid's internal friction or resistance to flowing. Syrup would be an example of a fluid with high viscosity; beer would be an example of a fluid with low viscosity. Oils can come in a wide range of viscosities, from very low for light lubricants like "3-In-One" oil and spray to moderately low for car motor oils to high for gear oils to very high for stuff like STP Engine Treatment. The viscosity of many fluids changes with temperature. Pancake syrup, for example, is much more viscous when it is cold than when it is hot. We can even discuss viscosity in terms of bodily fluids like blood (for example, LDL cholesterol tends to increase blood viscosity).

Oil viscosity is indicated by its "weight" numbers, such as 10W-30. The Society of Automotive Engineers (SAE) rates the viscosity of oil at winter temperatures and at temperatures near that of boiling water.

Oils rated by the SAE for winter requirements have a "W" after the viscosity rating (example: 10W); and oils are rated for the high temperature requirements have no letter (example SAE 30). Thus 5W-30 oil is less viscous than 10W-30 when cold, but has the same viscosity when hot. Likewise, 10W-40 oil has the same viscosity when cold as 10W-30, but is less viscous when hot. Some gear oils have viscosity ratings of 80W or above.

If an object is moved through a viscous fluid at velocity v as shown in the figure, it will experience a viscous force F acting opposite the direction of motion. The friction force is given by

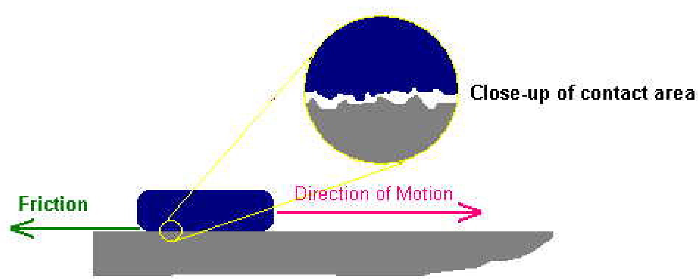


$$\mathbf{F = - b\ v}$$

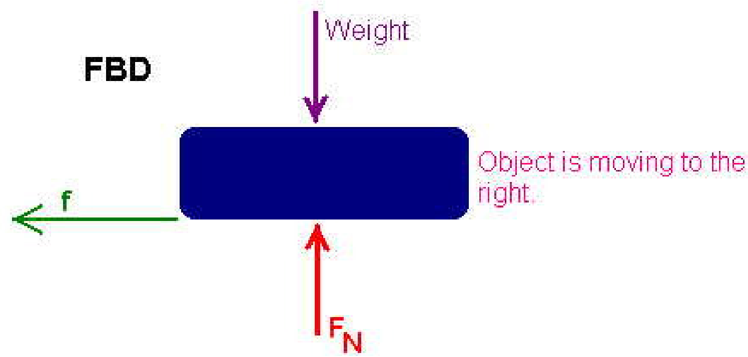
where b depends on the size and shape of the object and the viscosity of the fluid. The negative sign means the force acts opposite the direction of motion.

Solid-on-Solid Friction

When one solid object slides across another solid object, friction occurs. This friction is generally due to irregularities in the surfaces the microscopic level. This is the kind of friction that makes it tough to drag a couch across a floor.

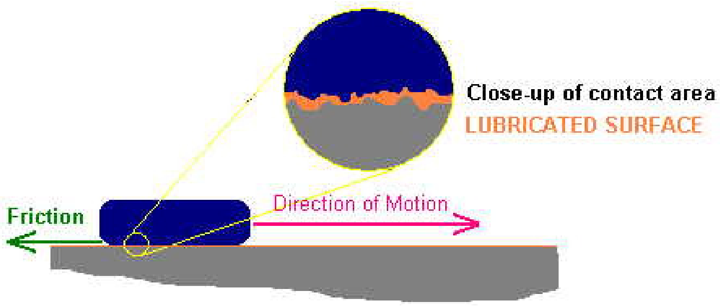


This type of friction is called kinetic friction. The friction force **f** depends in part on the contact force between the two objects (known as the Normal force $\mathbf{F_N}$). It also depends on the characteristics of the two surfaces making contact. This second factor is described by a *coefficient of kinetic friction* (μ_k). These are related by the equation



$$f_k = \mu_k F_N$$

A large μ_k indicates that the two surfaces are not "slippery" -- e.g. rubber on concrete has μ_k of approximately 0.8. A small μ_k indicates that the two surfaces are "slippery" -- waxed wood on wet snow has a μ_k of approximately 0.1.



When a lubricant is placed between the two surfaces, μ_k usually gets significantly smaller. This is because the lubricant fills in and smoothes out the surfaces' roughness.

There is a second type of solid-on-solid friction -- the type that occurs when two objects are in contact but are <u>not</u> sliding over one another. This is the friction that keeps the foot of a ladder in place when it is leaning against a wall. This is known as <u>static</u> friction and can vary between zero and some maximum value. The maximum force of static friction is given by

$$f_s = \mu_s F_N$$

where μ_s is called the *coefficient of static friction*. Static friction should perhaps be called static "friction" (note quotes). After all, in static friction there is no motion and no heat production, but it works in the same sort of way as kinetic friction so we call it friction, too.

For most materials, the static coefficient of friction between two surfaces is larger than the kinetic coefficient, meaning that static friction is stronger than kinetic friction. This is one of the principle concepts behind anti-lock braking systems (ABS) on cars -- if the wheels can be kept rotating while the car stops, static friction between the tires and the road acts to stop the car; if the wheels lock up (and the tires slide on the pavement), then the weaker force of kinetic friction does the stopping.

Note that for both static and kinetic friction, the only things that matter are the surfaces and the normal force. Area of contact, etc. has no bearing on the amount of frictional force present.

A table of friction coefficients has been added to the class web page.

Friction Formulas are Approximate!

Friction is a very complex phenomenon, and the formulas we have learned for air drag, viscous friction, and solid-on-solid friction are only approximations that have been found to work reasonably well.

Example Problem #1:

A parachute has a drag coefficient of 1.4. What diameter must a parachute have if a 200 lb man using it is to have a terminal velocity of 10 mph?

Solution:

$W = 200 \text{ lb} = 889.6 \text{ N}$
$\rho = 1.29 \text{ kg/m}^3$ (air density – looked it up)
$C_d = 1.4$
$V = 10 \text{ mph} = 4.4703 \text{ m/s}$

At terminal velocity W = D as shown at right…

$$W = D$$

$$889.6 \text{ N} = \tfrac{1}{2}(1.29 \text{ kg/m}^3)(1.4)(A)(4.4703 \text{ m/s})^2$$

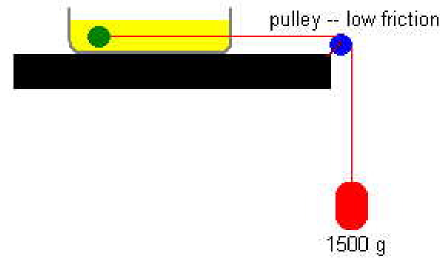
$$\frac{2(889.6 \text{ N})}{(1.29 \text{ kg/m}^3)(1.4)(4.4703 \text{ m/s})^2} = A = 49.298 \text{ m}^2$$

$$\pi r^2 = A = 49.298 \text{ m}^2$$

$$r = 3.961 \text{ m}$$

$D = 2r = 7.923 \text{ m} = 26$ ft in diameter.

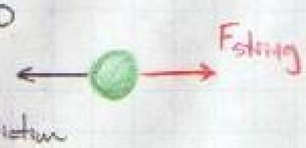
Example Problem #2:



In the figure at right, the yellow fluid is a highly viscous oil. The mass falls at a constant 0.5 m/s. Determine the "b" value for the viscous friction.

The force of viscous friction is acting on the green ball:

FBD



The string acts on both.

The falling weight:

FBD

$m = 1500\,g = 1.5\,kg$

$v = 0.5\,m/s$

Since v = constant acceleration is zero for both objects. Net force is zero for both. So

$W = F_{string} \quad F_{string} = F_{friction}$

So $W = F_{friction}$

$mg = bv$

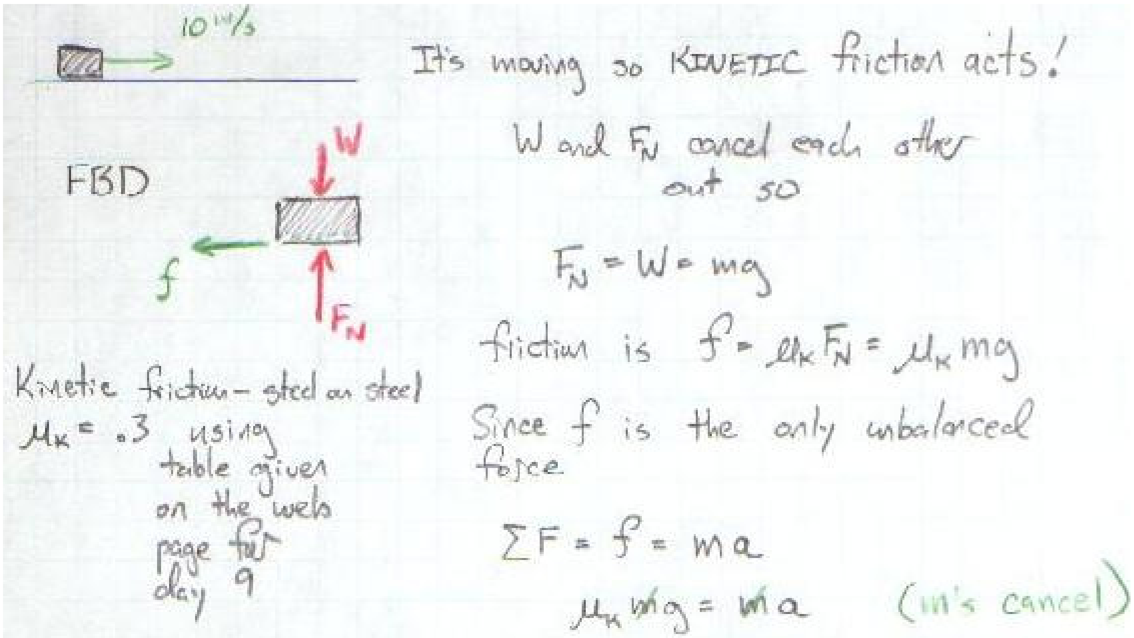
$1.5\,kg\,(9.8\,\frac{N}{kg}) = b\,(0.5\,m/s)$

$14.7\,N = 0.5\,(m/s)\,b$

Answer: $29.4\,\frac{Ns}{m} = b$

Example Problem #3:

A steel block is sliding across the floor at 10 m/s. If the floor is also made of steel, how long will it take the block to stop?



10 m/s

It's moving so KINETIC friction acts!

FBD

W

f

F_N

W and F_N cancel each other out so

$F_N = W = mg$

friction is $f = \mu_K F_N = \mu_K mg$

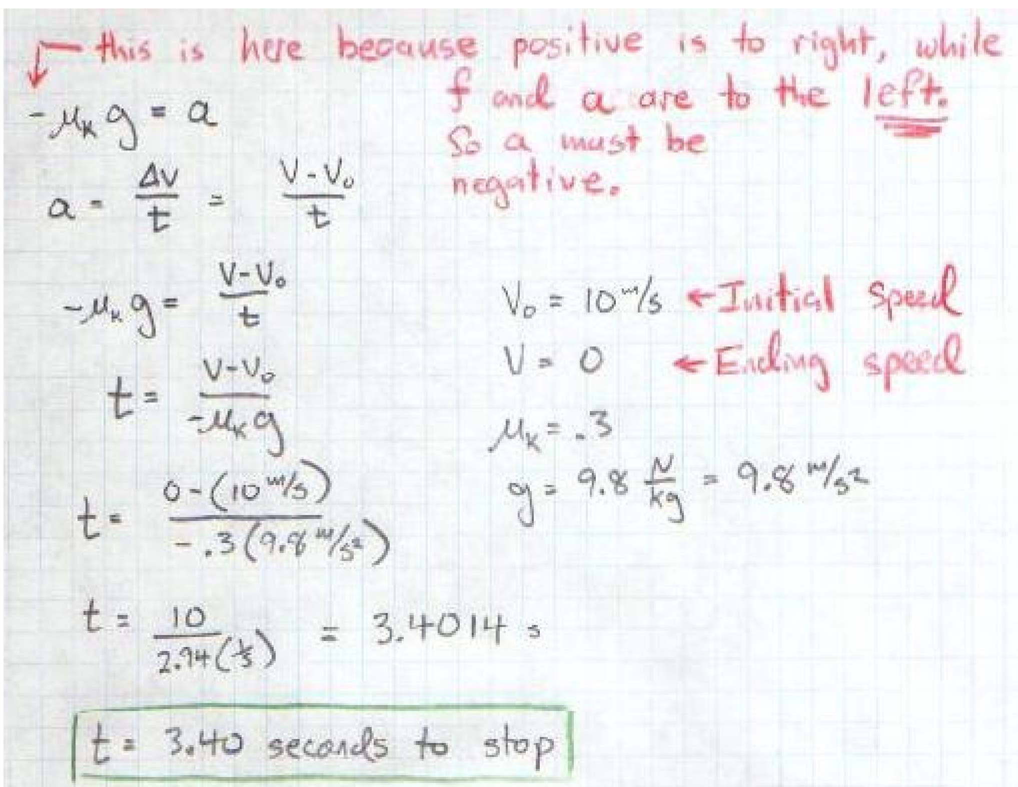
Kinetic friction – steel on steel

$\mu_K = .3$ using table given on the web page for day 9

Since f is the only unbalanced force

$\Sigma F = f = ma$

$\mu_K mg = ma$ (m's cancel)



this is here because positive is to right, while f and a are to the left. So a must be negative.

$-\mu_K g = a$

$a = \frac{\Delta V}{t} = \frac{V - V_0}{t}$

$-\mu_K g = \frac{V - V_0}{t}$

$t = \frac{V - V_0}{-\mu_K g}$

$t = \frac{0 - (10\ m/s)}{-.3(9.8\ m/s^2)}$

$t = \frac{10}{2.94\left(\frac{1}{s}\right)} = 3.4014\ s$

$V_0 = 10\ m/s$ ← Initial speed

$V = 0$ ← Ending speed

$\mu_K = .3$

$g = 9.8\ \frac{N}{kg} = 9.8\ m/s^2$

t = 3.40 seconds to stop