Chapter 5
Newton's Laws Chapter Review

EQUATIONS:

- $f_k = \mu_k N$ [This is the *kinetic friction* expression, where μ_k is the coefficient of kinetic friction and N is the normal force applied to the body in question. Note that there is only one kinetic frictional force between two surfaces. It is *not* a velocity dependent quantity, assuming you don't change the characteristics of the surfaces through, say, heating during the slide.]

- $f_s = \mu_s N$ [This expression, which is associated with *static friction*, looks very much like the expression for kinetic friction. In it, μ_s is the coefficient of static friction and N is the normal force applied to the body in question. What makes the two expressions different is that f_s is defined as the MAXIMUM possible static friction force between two surfaces (whereas there is only *one* possible kinetic friction force). Also, f_s will always be larger than f_k.]

- $F_{net,x} = ma_x$ [This is Newton's Second Law, where $F_{net,x}$ is the net force on a body in the *x direction*, m is the body's mass, and a_x is the body's acceleration in the *x direction*.]

- $a_c = v^2/R$ [This is the centripetal acceleration expression, where v is the magnitude of the body's velocity and R is the radius of the circle upon which the body moves. The center seeking direction is ALWAYS perpendicular to the motion and always toward the CENTER of the path upon which the body moves.]

- $a = dv/dt$ [This is the acceleration relationship needed whenever a time-dependent velocity is requested. Remember that in problems like this, the acceleration direction (assumed to be along the line of motion) will be positive or negative *depending upon the sign of the velocity vector*. If this isn't clear, review the section associated with this kind of problem.]

- $F_{grav} = mg$ [This is the gravitational force exerted by the earth on mass m (it is also called *the mass's weight*). The constant g is the magnitude of the acceleration of gravity close to the surface of the earth, or 9.8 m/s^2 in the MKS system.]

COMMENTS, HINTS, and THINGS to be aware of:

- **Newton's three laws** are:
  --1.) In an *inertial frame of reference*, bodies in motion tend to stay in motion with a constant velocity, and bodies at rest tend to stay at rest, unless impinged upon by an external force.
  --2.) The sum of the forces acting in a particular direction on a body will equal the product of the body's mass and its acceleration in that direction. As a vector, this is written as $\mathbf{F} = m\mathbf{a}$.

--3.) For every action (i.e., for every *force*), there must be an equal and opposite reaction somewhere in the universe.

- The **five kinds of forces**:
  --Normal force: Forces that are provided by some kind of support. They are always perpendicular to the surface providing the support, and are usually symbolized by an N.
  --Frictional force: Kinetic friction is always opposite the direction of motion. Static friction is always opposite the direction the body *would* move should it break loose.
  --Gravitational force: Near the earth's surface, this is always down and equal to mg, where m is the body's mass and g is defined as the MAGNITUDE of the acceleration of gravity near the earth's surface. Note that the magnitude of this force is always symbolized by the product of m and g in free body diagrams, and the direction is denoted by a downward arrow.
  --Tension force: Always directed *away from* the body to which the rope or string is attached, tension forces are usually symbolized by a T, often subscripted.
  --Push-me pull-you force: Any force that doesn't fit into the other four categories. They are usually characterized by an F, often subscripted.

- A **free body diagram** is a sketch designed to allow you to identify all of the forces acting on a single body. Force directions are depicted with appropriately oriented arrows (gravity, for instance, is characterized by an arrow pointing down), and force magnitudes are denoted algebraically next to the arrow (i.e., gravity is mg, tension is T, etc.). When doing an f.b.d., mentally run through the *kinds* of forces that could exist within the system (i.e., is there gravity?--if so, put it in, etc.). Forget one force and you're dead.

- As is the case with all approaches in physics, Newton's Second Law is designed to allow you to write down mathematical relationships that are *true*. **Newton's Second Law** says that for a single body, if you pick ANY direction (x, y, or z) and sum up all of the positive and negative forces that act on the body along that line, the sum will equal the product of the body's mass m and its acceleration a along that line.

- **The Approach** for using N.S.L. is:
  --Look at the problem and think to yourself, *I couldn't possibly do this*. Then, start *The Approach*.
  --Pick ONE body in the system and draw a free body diagram for it. Make sure you don't leave any forces out, and be sure you accurately show the forces that exist (i.e., a *normal force* should be directed *perpendicularly out* relative to the support that provides it--DON'T draw an arrow that makes it look like it has a component that is *parallel* to the surface).
  --Through observation, identify the body's *line of acceleration*. Place one coordinate axis along that line. Place a second axis perpendicular to that line. For both axes, it is *your choice* which direction you will define as *positive* (axes *vertically up* and *horizontally to the right* are usually defined as positive, though they certainly don't have to be).
  --Break all forces that are not along either of the axes into their components along each axis.
  --Being careful about signs, sum the forces directed along one axis. Make that sum equal to the product of the body's mass and acceleration (i.e., ma_x), subscripting the acceleration term to match the axis (do this only if needed for clarity).
  --There are instances in which dealing with an acceleration *magnitude* is clearly easier than dealing with an acceleration term that has a possible negative sign embedded within it. If you prefer to work with a magnitude instead of an acceleration vector (embedded sign and all), you can make the acceleration into a magnitude by unembedding the sign. That is, if

you think that the body is accelerating in the negative direction, relative to the positive axis direction as you've defined it, make the right side of N.S.L. equal to *-ma*.

--If you can, use the resulting expression to solve for the unknown you are seeking. If not, and you find more unknowns in the relationship than you have equations, either repeat the process along the other coordinate axis or, if that doesn't help, pick another body in the system and start the whole process over again.

--By the time you are done, you should have enough equations to eliminate all of the unwanted unknowns and solve for the desired quantity.

• N.S.L. and **center seeking (centripetal) forces and acceleration**:

--According to Newton's First Law, bodies in motion continue to move in a straight line unless impinged upon by a force. Forces that change the ***direction*** of a body's velocity vector (versus changing the *magnitude* of the body's velocity vector) are called *center seeking forces*, or *centripetal forces*. A centripetal force is NOT a new *kind* of force. The phrase *centripetal force* is a label that is used to identify any naturally occurring force in a system that changes the *direction* of a body's motion.

• Centripetal forces produce a centripetal acceleration. The **centripetal acceleration** a body experiences as it moves in a circular path is related to two quantities: the radius R of the body's path and the magnitude of the body's velocity v. The actual expression is $a_c = v^2/R$.

• One of the steps in the N.S.L. approach is to determine the **directions of the coordinate axes**. If you will remember, one axis is always directed along the line of the acceleration (this is important because the sum of the forces along that direction will equal *ma*, where *a* is often the parameter you are trying to determine). When a body is being pushed or pulled out of straight line motion, there must exist a single force, the component of a single force, or, possibly, a combination of forces and components, that act centripetally. The net **centripetal acceleration** generated by those forces will **ALWAYS** be **aimed** toward *the center of the circle* upon which the body is being forced to travel, and the magnitude will always be v^2/R.

• One of the hardest things for students to do is to **determine *when*** it is appropriate **to use v^2/R** (i.e., to identify when a centripetal situation exists). The best way to tell is to *look to see if the body is following a curved path* (i.e., is the body's direction changing?). If it is, there must be a naturally occurring force (gravity, tension, a component of a normal force, whatever) that is directed *toward the center of the circle* upon which the body is moving. Pick that direction for one axis, then use the N.S.L. approach as outlined above.

• A corollary to the above observations is the following: The most confusing characteristic of centripetal situations is that **centripetal acceleration** is always **PERPENDICULAR** to the **line of the motion** (i.e., to the direction of the velocity vector). Students become comfortable with inclined plane problems in which the acceleration in the *normal* direction (i.e., perpendicular to the direction of motion) is equal to *zero*. If you get in the habit of mindlessly zeroing the acceleration variable directed perpendicular to the motion, you will be lost when you run into a centripetal force problem. You need to LOOK AT THE PROBLEM, then decide what should and shouldn't be equal to zero.

• One bit of nastiness that sometimes arises is found in situations in which you are asked to determine the **velocity** of a body's motion **as a function of time** knowing nothing more than the forces acting on the body. *The Approach* works just fine with this kind of problem, but there is one major difference in how you proceed. The acceleration, assumed to be along the line of motion, must be written as dv/dt. ALSO, the *sign* of that dv/dt term should *not* be determined by assuming an acceleration direction, then unembedding the acceleration sign as is done in, say, an inclined plane problem. The sign that goes in front of the dv/dt term must be determined by taking the derivative of the velocity vector as written in the form $\mathbf{v} = v(\underline{+}\mathbf{i})$. Although you will most probably drop the unit vector, the appropriate sign will fall out with the derivative.