Forces

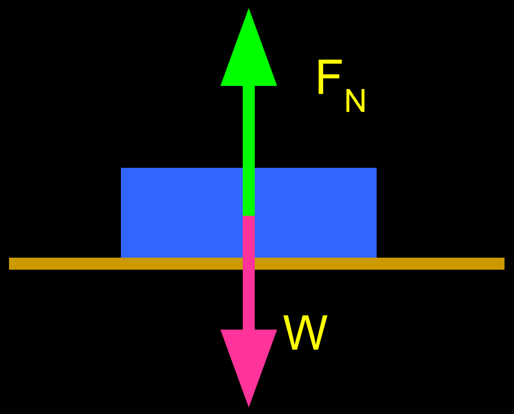
- Weight (W)
  - Units: Newtons
  - Weight is the force due to gravity upon an object
    - Since the force is gravity, the acceleration that is caused by the force must be the acceleration due to gravity

$$F_{Net} = ma$$

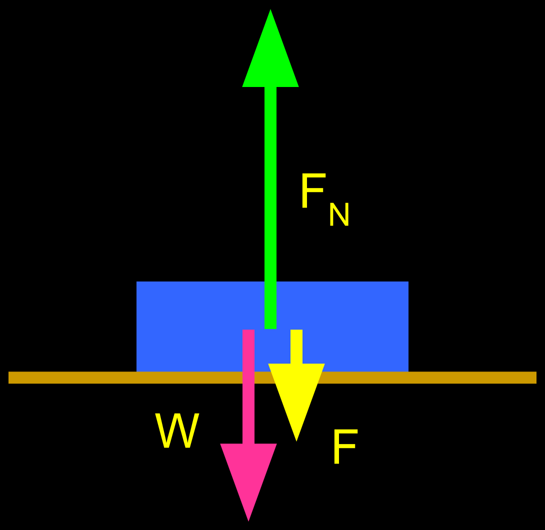
$$F_{Gravity} = W = mg$$

- Normal Force (F_N)
  - The normal force is a contact force
    - A contact force is a force that only exists when two objects are in contact with each other
    - Typically will occur when an object is resting on a surface
  - The normal force always occurs in a direction that is normal to the surface of contact
    - Don’t know what the word “normal” means in mathematics? Look it up!
  - Magnitude of the normal force depends on how hard the objects are being pressed together
    - The harder they are being pressed together, the larger the normal force

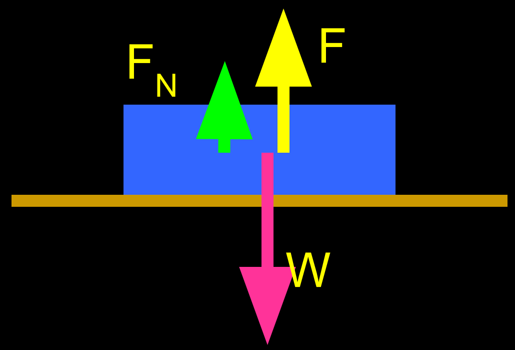
– Consider a book resting on a table
  - The book is resting on the table, therefore its acceleration is zero
  - The acceleration of the book is zero, therefore the net force on the book is zero
  - The net force on the book is zero, therefore the net force in the y-direction is zero
  - This means that the forces pointed up must be equal to the forces pointed down
    – For the book (and for that matter any object that is just resting on a surface) the only two forces are the normal force and the weight
    – Since the net force in the y-direction is zero, the normal force and the weight are equal to each other
      » $F_N = W$



- How would the normal force change if I started pressing down on the book?
  - If I am pushing down on the book, there are two forces in the downward direction, my pushing force and the weight
  - The net force in the y-direction is still zero, therefore the normal force must increase to counter both forces
  - In this case, $F_N = W + F$



- How would the normal force change if I started lifting up on the book?
  - If I am lifting up on the book, there are two forces in the upwards direction, my lifting force and the normal force
  - The net force in the y-direction is still zero, therefore the normal force must decrease to counter both forces
  - In this case, $F_N + F = W$



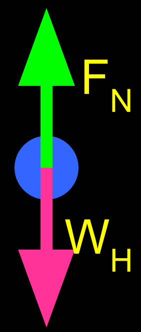
– Example

- During a circus balancing act, a woman performs a headstand on top of a man's head. The woman weighs 490 N and the man's head and neck weight 50 N. It is primarily the seventh cervical vertebra in the spine that supports all the weight above the shoulders. What is the normal force on this vertebra before and during the act.
  – Get the given written down along with the free-body diagrams

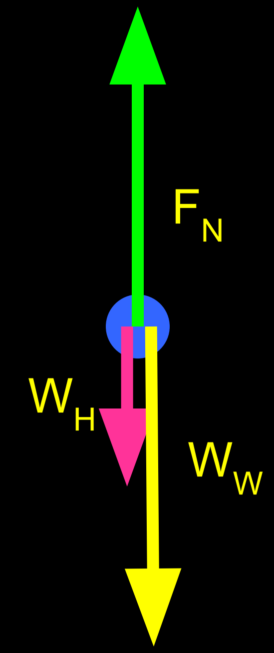
$W_{Head} = 50\text{ N}$

$W_{Woman} = 490\text{ N}$

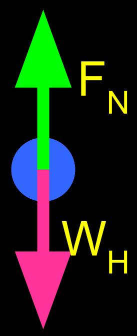
Before the Act:



During the Act:



Before the Act:

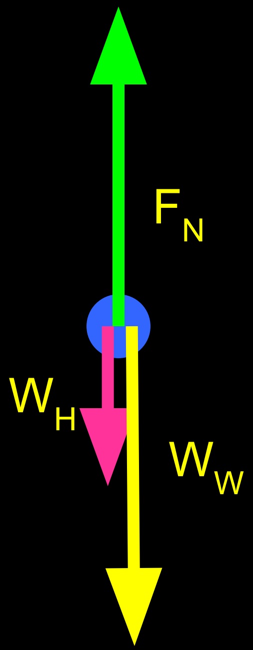


Before the act, the man's head is not accelerating, therefore the net force is zero

If the net force is zero, then the normal force is equal to the weight

$F_N = 50$ N

During the Act:



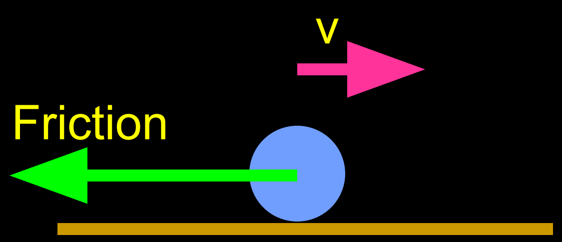
During the act, the man's head is still not accelerating, therefore the net force is still zero

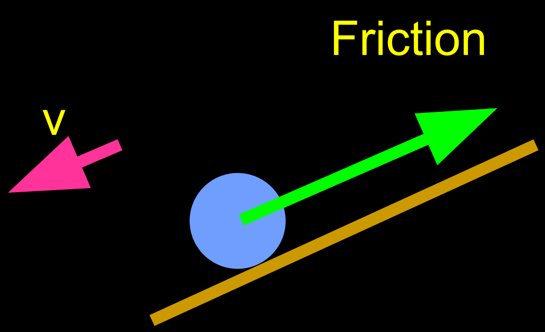
Therefore $F_{net} = F_N - W_H - W_W = 0$

Therefore $F_N = W_H + W_W$

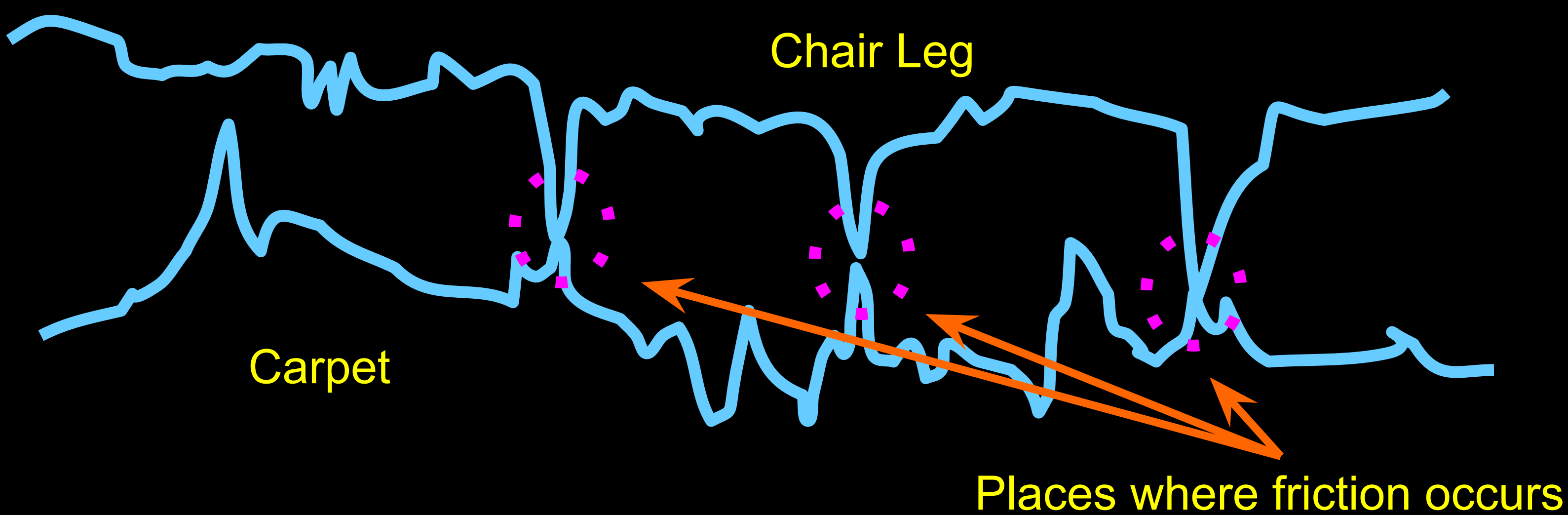
$F_N = 540$ N

- Frictional Forces
  - Friction is a contact force
    - What must be true in order to have a contact force?
  - Friction always is in the direction that is against the motion (or would be motion) of the object
    - This means that friction is always points in a direction parallel to the surface

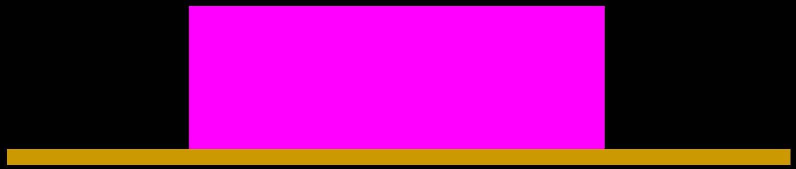




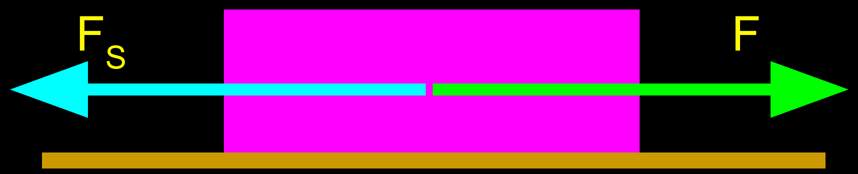
- Origins of the Friction Force
  - When two objects are in contact with each other, they are in contact at relatively few points
    - Even with highly polished surfaces, the points of contact are microscopic
  - The points of contact are close enough that the molecules exert intermolecular forces on each other
  - We call these intermolecular forces friction



- Static Friction Force (F_s)
  - The word static, if you did not know, means “not moving”
    - So, if two objects (or an object and a surface) are in contact with each other and there is no motion between the two, then the friction I could have is called static friction
    - What do I mean by motion between the two?
  - Picture a block sitting on a table
  - If there are no horizontal forces acting on the block then there is no static friction
    - $F_S = 0$
    - The friction force is zero because there are no horizontal forces for the friction to oppose



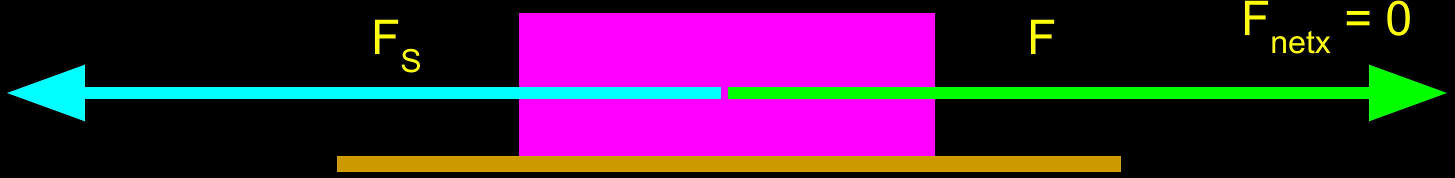
– If I apply a force to the book and it does not move, then the net force on the book is zero
  - Meaning that the force I push with must be cancelled out by the static friction force
  - Meaning that the static friction force is equal to the force I am exerting



$F_{netx} = 0$

– If I increase the force I exert on the book and it still does not move, what can I say about the static friction force?
  – The static friction force must increase to cancel the force I exert

$F_{netx} = 0$



- The static friction force will continue to grow and equal the applied force until the static friction force reaches its maximum value
  - F_S^{Max} stands for the maximum static friction force
- If I increase the applied force above F_S^{Max} the object will accelerate
  - This is because there is now a non-zero net force
- Thus, the magnitude of F_S is equal to the applied force and is less than or equal to F_S^{Max}

$$F = F_s \quad when \quad F_s \leq F_s^{MAX}$$

- Experimental evidence has shown that F_S^{Max} has two characteristics
  - First, that F_S^{Max} is independent of the area of contact
    - Meaning that the amount of area of the object that is touching the surface does not affect the amount of static friction
  - Second, that F_S^{Max} is proportional to F_N
    - The harder the surface pushes on the object, the more contact points between the surface and the object
    - The more contact points, the stronger the static friction force

$$F_s^{MAX} \propto F_N$$

F_S^{Max} is proportional to F_N

- In order to turn my proportion into an equation, I need a proportionality constant
  - The proportionality constant that makes F_S^{Max} equal to F_N is called the coefficient of static friction
- Coefficient of Static Friction (μ_s)
  - The coefficient of static friction is just a number that is found through experiments
    - It is based off of the types of materials in contact, the condition of the materials, and other variables
    - Typical values range from .01 for smooth surfaces to 1.5 for rough surfaces

$$F_S^{MAX} = \mu_S F_N$$

- Kinetic Friction (F_k)
  - The word kinetic means "motion" however kinetic friction only applies when an object is sliding over a surface (or another object)
    - As the object slides over the surface, each will exert a force on the other that opposes the motion
    - This is called kinetic or sliding friction force (F_K)
  - Experimental evidence shows that F_K has three characteristics
    - First, that F_k is independent of the area of contact
      - Meaning that the amount of area of the object that is touching the surface does not affect the amount of static friction
    - Second, that F_k is proportional to F_N
      - The harder the surface pushes on the object, the more contact points between the surface and the object
      - The more contact points, the stronger the static friction force
    - Third, F_k is independent of the speed of the sliding motion, if the speed is small

- Once again, there needs to be a proportionality constant to make F_K equal to F_N
  - This constant is called the coefficient of kinetic friction
- Coefficient of Kinetic Friction (μ_k)
  - The coefficient of kinetic friction is just a number that is found through experiments
    - It is based off of the types of materials in contact, the condition of the materials, and other variables
    - Typical values range from .01 for smooth surfaces to 1.5 for rough surfaces
  - The values of μ_K are always less than μ_S for any two given surfaces
    - This is because it takes less force to keep an object sliding than it does to start an object sliding
  - Therefore, F_K is always less than F_S

$$F_k = \mu_k F_N$$

– Example (to be worked in class)

- A sled, traveling at 4 m/s, enters some snow. How far does the sled travel before it stops? The coefficient of kinetic friction is .05 and the mass of the sled is 38 kg.

  If the coefficient of static friction is .35, what is the force required to get the sled started moving again?

– Example (to be worked in class)
  - A car, sitting on a dry asphalt, starts to accelerate. If the coefficient of static friction between the tires and the road is .61 and the mass of the car is 1150 kg, what is the maximum force that the car can exert on the ground and still be able to drive? What is the maximum acceleration that the car can undergo?

- Drag Forces
  - Drag forces occur when a solid travels through a fluid
    - A fluid is any substance that flows
      - I.e. a liquid or a gas
    - Drag forces always point in the direction opposite the motion of the solid
      - This is because drag forces resist the motion of the solid
  - The resistance results from the molecules of the fluid colliding with the solid as it passes through the fluid
    - The more molecules that the solid will run into, the larger the drag force
    - How can the amount of drag force also be related to density?

- Air resistance is the most well known of the drag forces
- Air Resistance
  - Air Resistance is dependent on two things
  - First, air resistance depends on the shape of the object, specifically, the surface area presented to the resistance
    - The larger the surface area, the more molecules the object will run into per second
    - The more molecules the object runs into per second, the greater the air resistance
  - Second, it is dependent on the speed of the object
    - The faster the object is going, the more molecules the object is running into per second
    - The more molecules the object runs into per second, the greater the air resistance

- Tension
  - Tension is a force that acts through a rope or cable
  - If you pull on the end of a rope or cable, the force is transmitted down the rope to the object that is attached to the other end of the rope
  - If we assume that we are using a massless rope, there is no loss of force
    - If the rope or cable has a mass, then some of the force applied goes into accelerating the rope or cable
    - This force is “used up” so there is a net loss of force from one end to the other
    - This is why we are going to make the assumption that ALL ropes and cables in this class are massless

- Equilibrium
  - Equilibrium refers to a lack of change, specifically, the velocity is not changing
  - If an object is in equilibrium, then the acceleration of the object is equal to zero
  - If an object is in equilibrium, then the net forces are equal to zero
  - Since force is a vector, the force in each direction is also zero
    - The two equations below will be the two equations that we will use to solve equilibrium problems

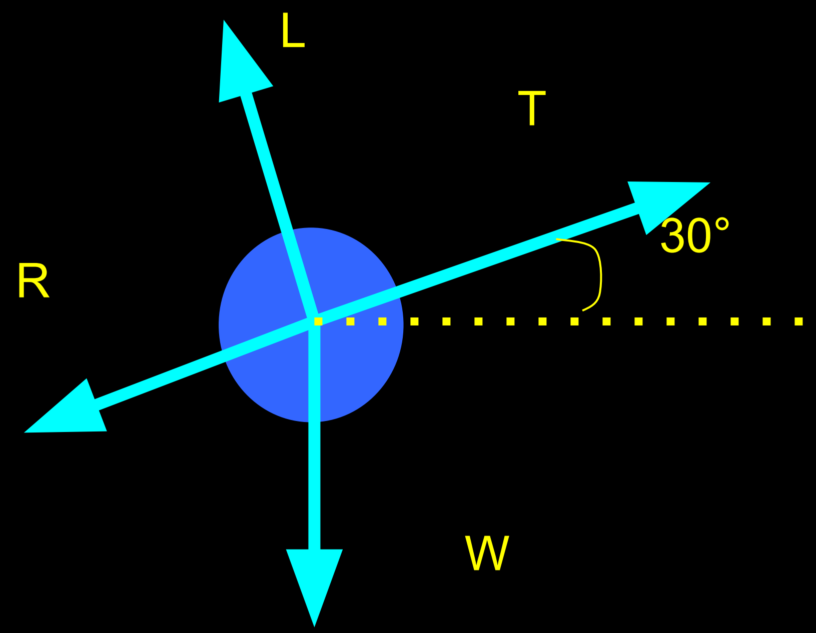
$$F_{net_x} = 0$$

$$F_{net_y} = 0$$

- Strategy for Solving Problems
  - Select the system (object) that you are going to apply the two equilibrium equations to
  - Draw a free-body diagram for the system
  - Choose a convenient coordinate axes for your problem
  - Apply the two equilibrium equations to the system
  - Solve the two equations for the unknown variable
    - We will solve the next three examples in class
    - Write down the givens, leaving about ½ a page below where you can put the example work

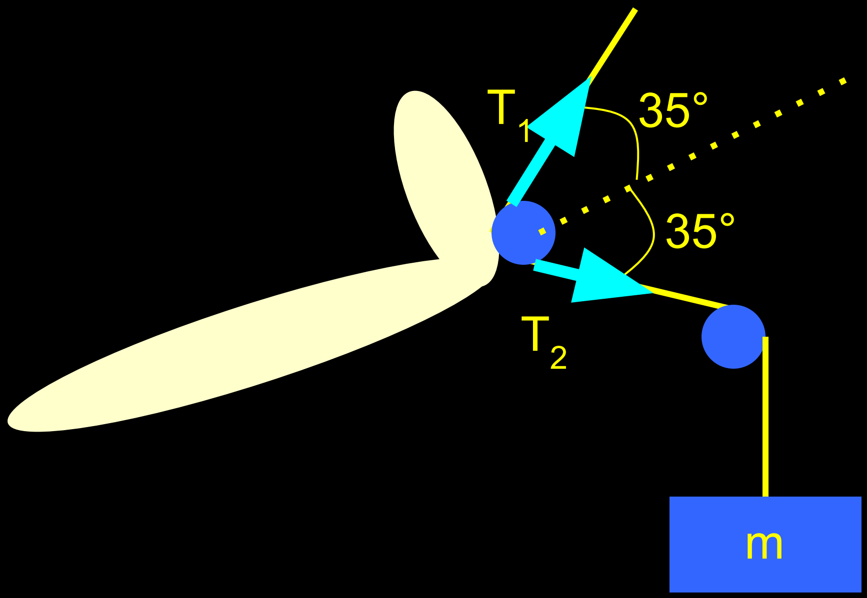
– Example 1

- A jet plane is flying with a constant speed along a straight line, at an angle of 30° above the horizontal. The plane has a weight whose magnitude is 86,500 N. Its engines deliver a thrust of 103,000 N. In addition, the lift force and air resistance act on the plane. Find L and R.



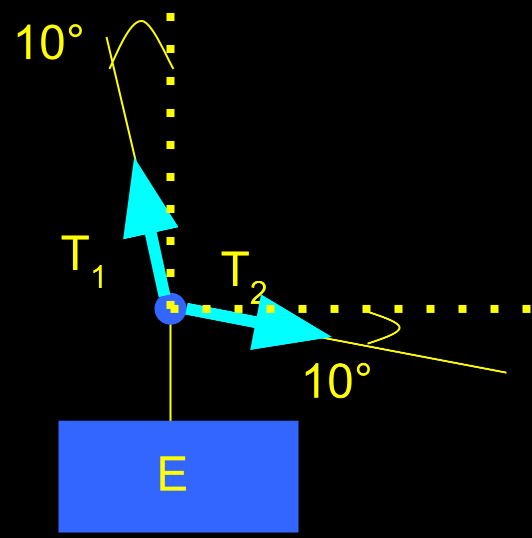
– Example 2

- The traction of a foot is pictured below. A 2.2 kg mass creates tension in a rope that runs around two pulleys. Because the same rope creates both tensions, T_1 and T_2 have the same magnitude. Find the magnitude of F, or the force of the foot on the foot pulley.



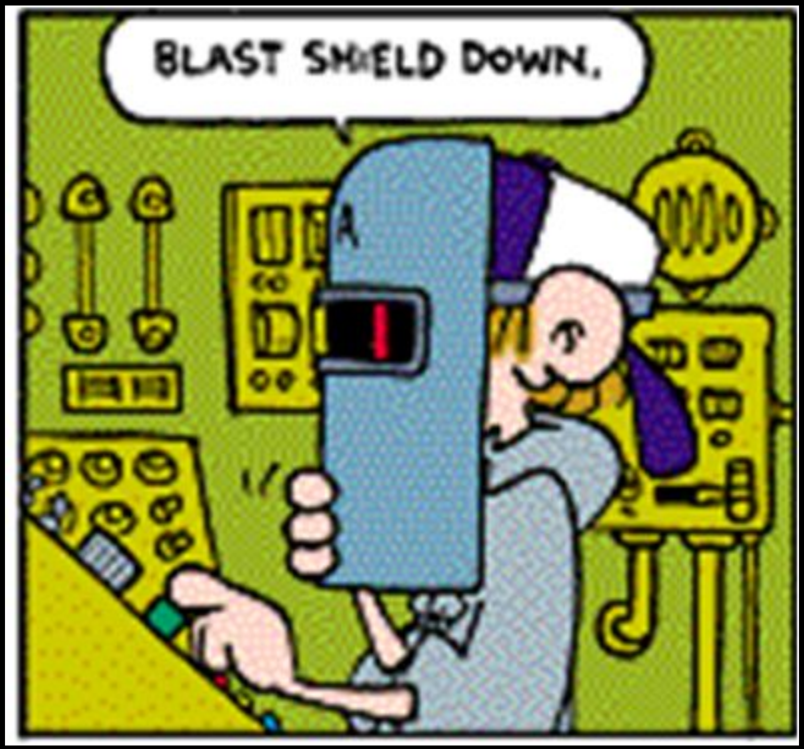
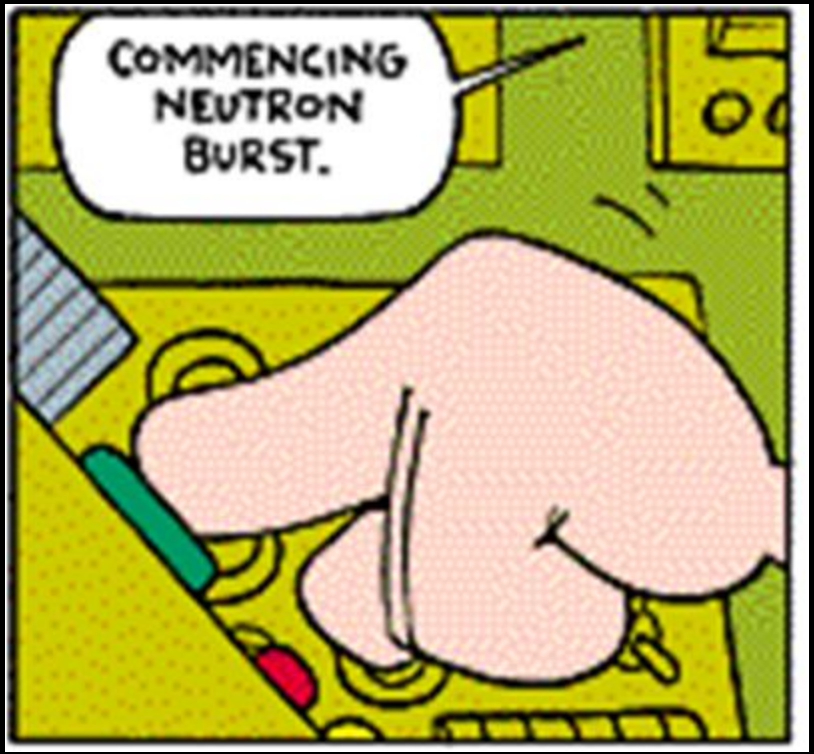
– Example 3

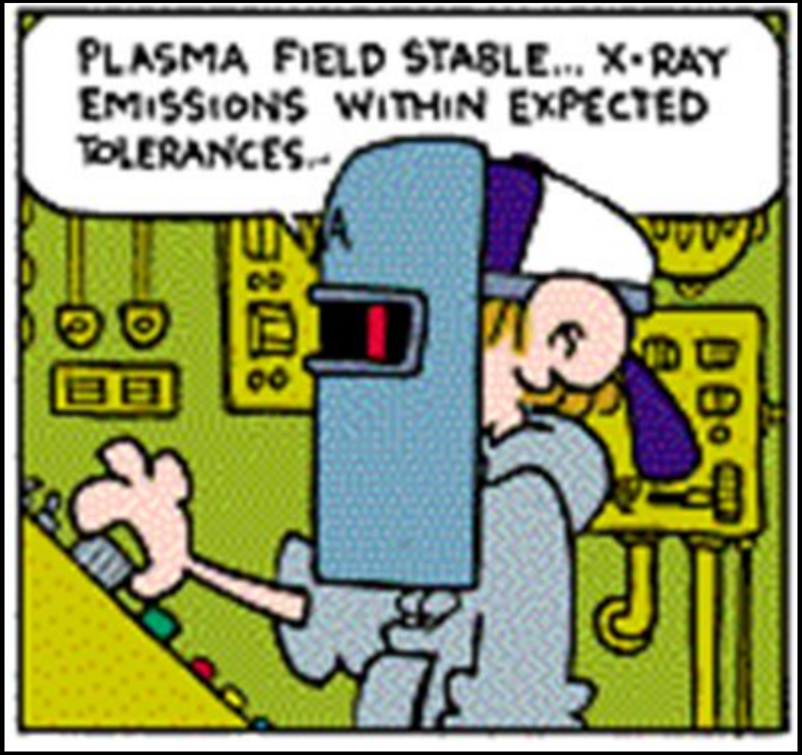
- An automobile engine has a weight of 3150 N. The engine is being put into a car as the diagram shows below. To position the engine, a worker is using a rope. Find the tension T_1 in the supporting cable and T_2 in the positioning rope.

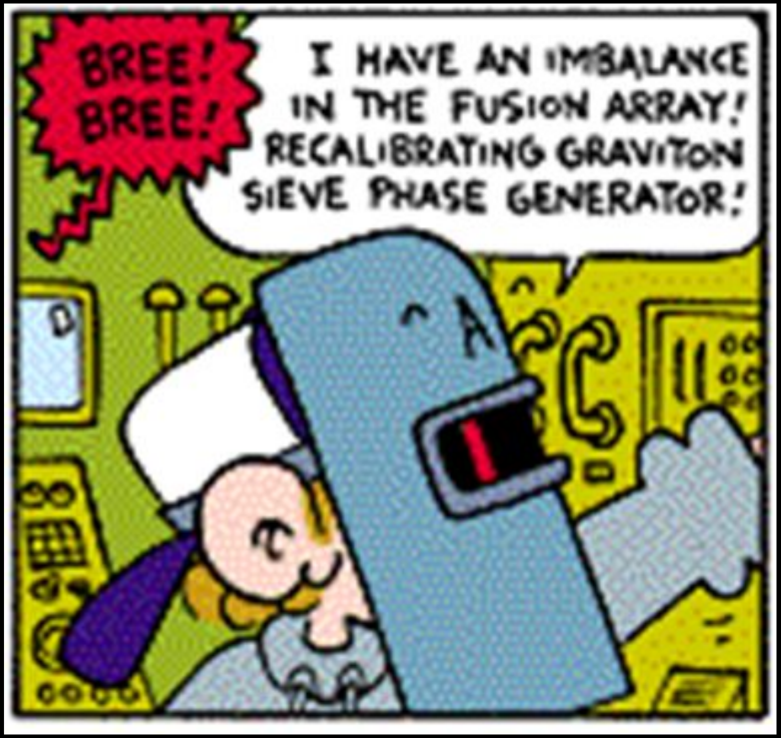


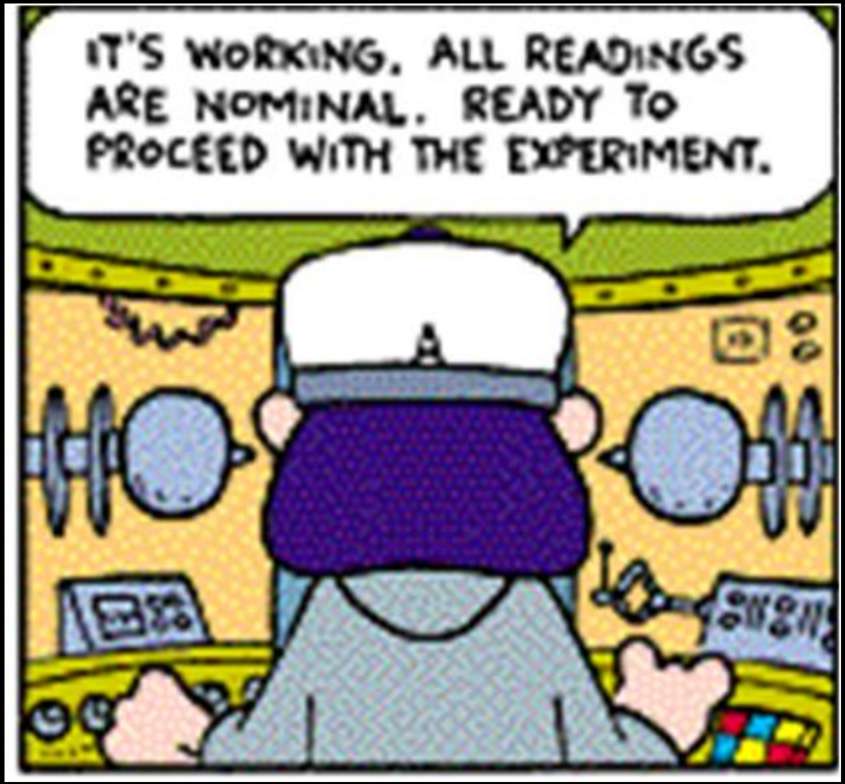
FoxTrot

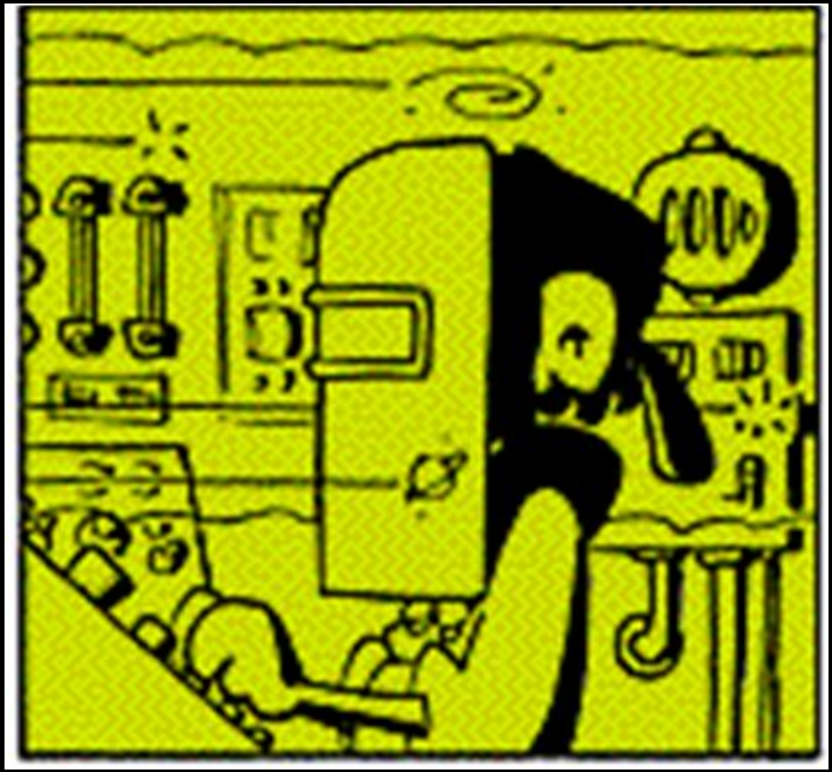
by Bill Amend

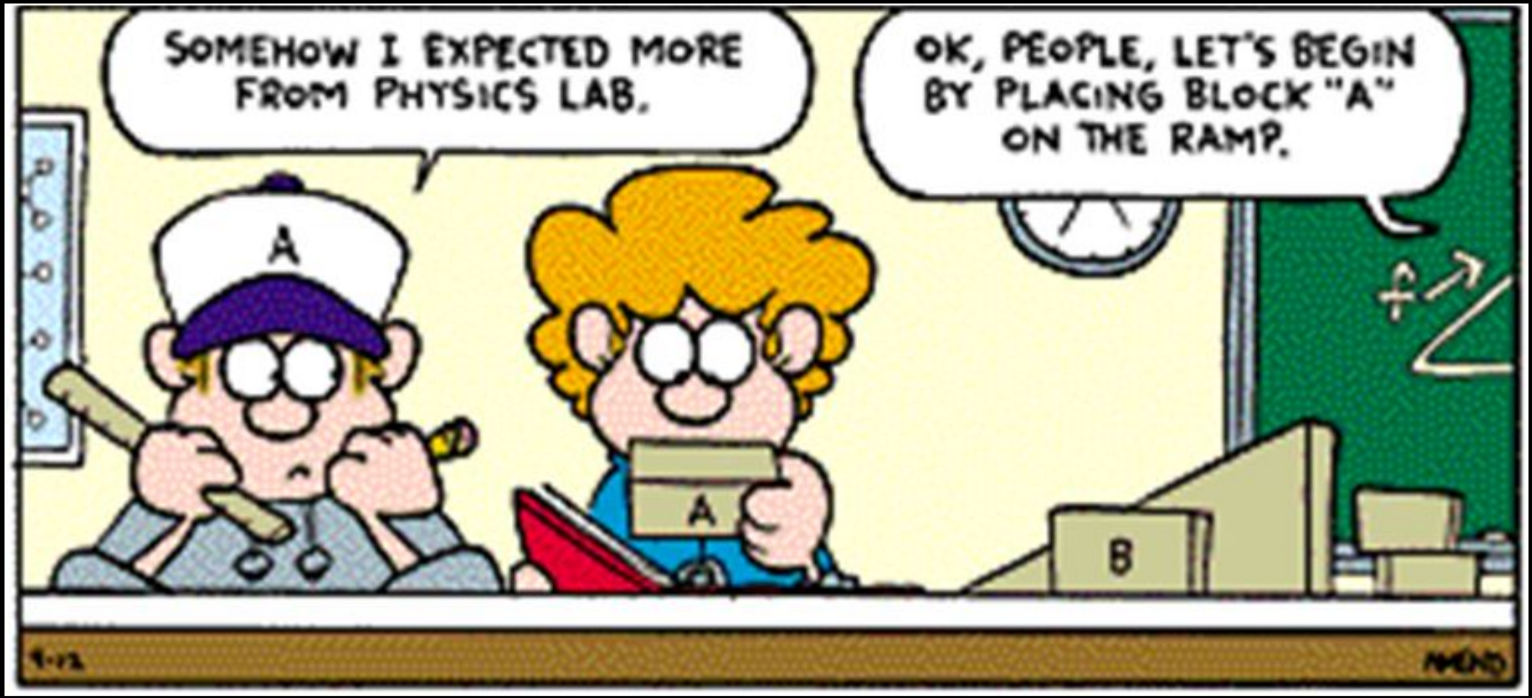

BLAST SHIELD DOWN.

COMMENCING NEUTRON BURST.


PLASMA FIELD STABLE... X-RAY EMISSIONS WITHIN EXPECTED TOLERANCES...


BREE! BREE!
I HAVE AN IMBALANCE IN THE FUSION ARRAY! RECALIBRATING GRAVITON SIEVE PHASE GENERATOR!


IT'S WORKING. ALL READINGS ARE NOMINAL. READY TO PROCEED WITH THE EXPERIMENT.




SOMEHOW I EXPECTED MORE FROM PHYSICS LAB.
OK, PEOPLE, LET'S BEGIN BY PLACING BLOCK "A" ON THE RAMP.