Physics A Unit 4 Equilibrium Forces

This unit will begin your study of Newton's Laws of Motion. Parts of the first two laws were already known and parts were first proposed by Newton. His contributions were revolutionary leaps forward concerning our understanding of the universe. In this unit you will concentrate on the first law of motion. There are obvious short-cuts in this unit that will almost guarantee an A on this test and an F on the next two tests. Do things the way this unit suggests and later units will have more continuity; you will have less stress and suffering. Before taking the test on Unit 4 you should be familiar with all of the areas outlined below:

I. Mass

II. Forces Defined

  A. Weight

  B. Tension

  C. Normal

  D. Friction

III. Newton's First Law of Motion

  A. Condition required for this law

  B. Resulting types of motion

This unit should take about six days to cover. The first day will consider mass and weight. Day two will investigate the tension force. Day three will explore the method for finding the normal force. Day four will analyze the force of friction. Day five is small group work with practice and review. Day six is test day.

<u>Newton's First Law of Motion</u>

If balanced forces act upon an object the object must <u>either</u>

  1) remain at rest <u>or</u>

  2) move with constant speed along a straight line

The reverse statement is also true. When you see an object with either type of motion then it has balanced forces acting on it.

Lesson 1-17 Weight and Mass

Your physics course up to this point has looked at different ways that an object can move. You will now turn your attention away from "how things move" and focus on "what makes them move". To begin you must recognize the definition of **force**. A force is defined to be a push or pull. The symbol for force is "**F**", a vector quantity. Forces are measured in Kg times meters per second squared which has the name of Newtons. 1 N = 1 Kg∗m / s^2. The first half of this unit will introduce four specific types of forces and Isaac Newton's First Law of Motion. The second half of this unit will use the introduced forces to look at Newton's 2^{nd} and 3^{rd} Law of Motion.First Law of Motion

When the forces acting upon an object are balanced then an object will a) remain at rest or b) move along a straight line at constant speed.

If you see an object sitting still or moving in a straight line at constant speed you should realize that the forces acting on it will add to zero in every direction.

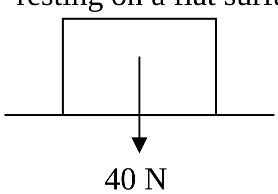
$$\Sigma F_x = 0 \qquad \Sigma F_y = 0 \qquad \Sigma F_z = 0$$

The above conditions can be used to get as many as three equations for three unknowns. First year physics usually uses only the first two conditions. You will now look at four special forces that show up in the two equations.

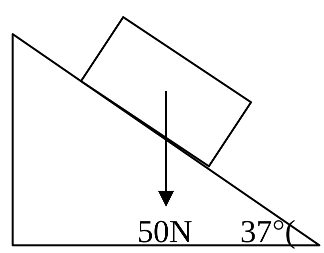
Weight

The force known as weight is a measure of how strong an object is gravitationally attracted to another. For several weeks you will specifically consider how hard the earth is pulling an object toward the center of the planet. The weight of an object will always be shown on a ***free-body diagram*** as an arrow drawn down from the center of an object. Consider the following examples:

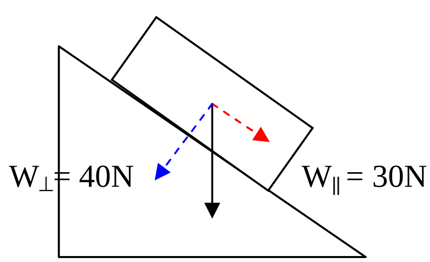
A 40 Newton object resting on a flat surface



A 50 N object on a 37° inclined plane



When an object is placed on an inclined plane you should always break the weight into a part that is parallel to the surface and a part that is perpendicular to the surface using the identities below:



$$W_{\perp} = W\cos\theta \qquad W_{\parallel} = W\sin\theta$$

You should recognize that the two parts of the weight on an inclined plane are the opposite and adjacent sides of a triangle with the total weight being the hypotenuse.

Often times in a physics problem either the weight or the mass of an object will be stated as a mere adjective in a problem. You may read something like "A 50 N object is …" or "A 5 Kg object is …". As soon as either weight or mass is given you should know the other value by default. The relation between weight and mass is given in the box to the right. At the surface of the earth weight has a value of ten times an object's mass. If the same object is taken from the surface of the earth to the surface of the moon then the weight will have a different value. The value of an object's mass cannot change without adding to or taking a way from the object. A 50 N object on the surface of the earth has a mass of 5 Kg. The same object taken to the surface of the moon would weigh 8.3 N with a mass of 5 Kg. To sum up the concept realize that mass is universal while weight depends upon how much gravitational acceleration exists from point to point in space.

$$W = mg$$

This leads to one final question, "What is mass?" Perhaps one of the most misunderstood ideas in physics. Mass is the measure of an object's inertia or resistance to change in motion. The more mass or inertia an object has the more difficult it will be to speed up, slow down or curve the object. Mass allows things at rest to remain at rest and things in motion to remain in motion. Why is it that you can throw a baseball easier than you can throw a bowling ball? It is also obvious from the previous equation that the more inertia an object has the more it will be attracted to the center of a planet. Why?

Checkpoints for this Lesson

- ✓ Write Newton's 1st Law of motion and demonstrate both conditions with appropriate examples.
- ✓ Draw the weight vector on a free-body diagram and break the weight into parts for objects on inclined planes.
- ✓ Given weight or mass of an object determine the mass or weight of the object.
- ✓ Explain the physical significance of mass as it is related to <u>inertial</u> properties.
- ✓ Compare and contrast weight and mass.

Practice Problems

For each of the following determine the weight of the object parallel to the surface, the weight of the object perpendicular to the surface and draw the free-body diagram.

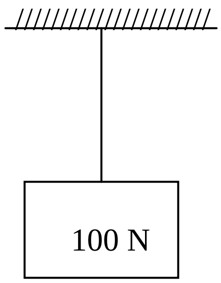
1. A 26 Kg object is placed on a 22.6° inclined plane.
2. A 34 Kg object is placed on a 28.1° inclined plane.
3. A 34 Kg object is placed on a 61.9° inclined plane.
4. A 100 N object is placed on a 16.3° inclined plane.
5. A 100 N object is placed on a 36.9° inclined plane.

	Total Weight	Parallel Weight	Perpendicular Weight
1	260 N	100 N	240 N
2	340 N	160 N	300 N
3	340 N	300 N	160 N
4	100 N	28 N	96 N
5	100 N	60 N	80 N

Lesson 1-18 **Tension***

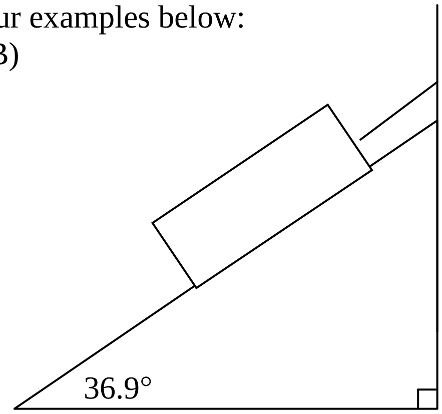
Tension is a force associated with a pull due to a string, cable, chain, cord, rope etc. Only when tension is associated with a rod can there be a push as well as a pull. For lightweight strings, cables, etc. tension is equal in value at opposite ends. Consider the tension in the lightweight strings for the four examples below:

A)



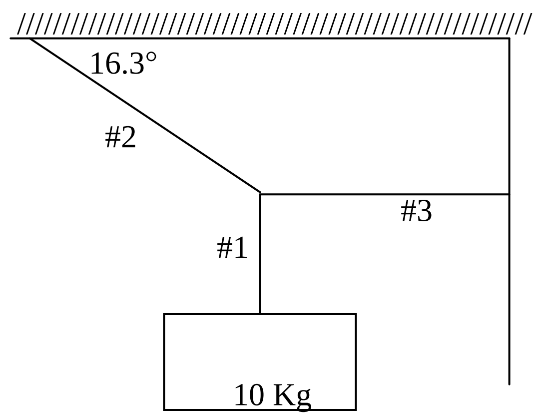
A 100 N object hangs from a ceiling.

B)

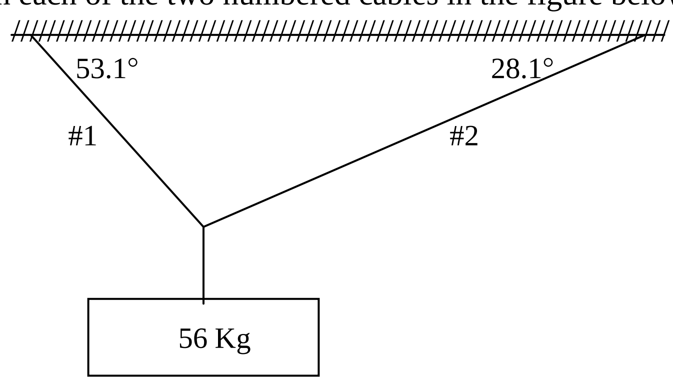


A 100 N object rests on a frictionless incline. A cable runs from the object, parallel to the incline and attaches to a vertical wall.

C) A 10 Kg object is suspended from a ceiling by three cables. Find the tension in each of the three numbered cables.



D) Find the tension in each of the two numbered cables in the figure below.



*Tension is also a 19th century expression for voltage as in a "high-tension wire".

For the previous examples set up your equations according to the following method.

a) {What pulls up?} – {What pulls down?} = {Does it Accelerate?}
   where the last question tells you to put zero if no and "ma" if yes.

b) {What pulls right?} – {What pulls left?} = {Does it accelerate?}

You should always sum the force parallel and perpendicular to the surface if possible.
Solutions to Example Problems:

A) $\Sigma F_y = T - 100\text{ N} = 0 \quad \therefore T = 100\text{ N}.$

B) $\Sigma F_{\|} = T - 100\sin(36.9°) = 0 \quad \therefore T = 60\text{ N}$

C) From the first example you should see that T_1 is equivalent to the object's weight. You can get two equations to solve for two unknowns by realizing that the forces acting on the knot will sum to zero.

$\Sigma F_y = T_2 \sin(16.3) - 100\text{ N} = 0$ $\quad \Sigma F_x = T_3 - T_2 \cos(16.3) = 0$

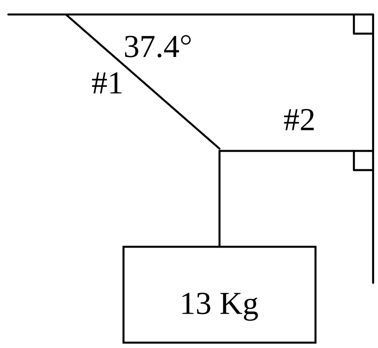
$T_2 = 356\text{ N}$ $\quad T_3 = 342\text{ N}$

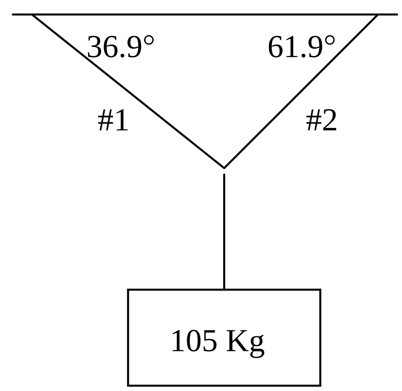
D) Again sum the forces acting on the junction of ropes for two equations/unknowns.

$\Sigma F_x = T_2\cos(28.1) - T_1\cos(53.1) = 0$ $\quad \Sigma F_y = T_1\sin(53.1) + T_2\sin(28.1) - 560 = 0$

Using any of the three methods from last week gives $T_1 = 500\text{ N}$ and $T_2 = 340\text{ N}$. I think that the matrix method is the easiest here.

Practice Problems: Find tensions in each of the following designated problems.

6.


7.


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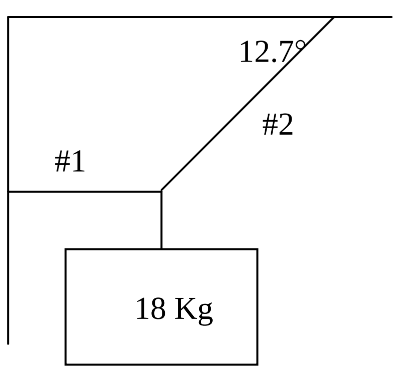
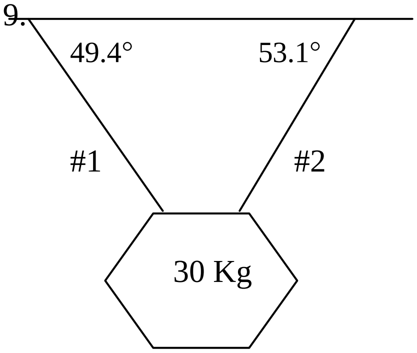


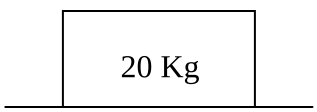
9.


Answers	T_1	T_2
6	214 N	170 N
7	500 N	850 N
8	800 N	820 N
9	184 N	200 N

Lesson 1-19 **Normal Force**

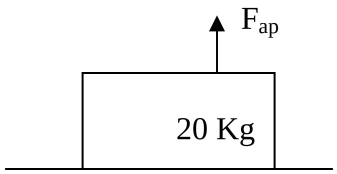
This force will show up in a *free-body* diagram anytime that an object is in contact with a surface. The normal force represents how hard the surface pushes on an object. The direction of the force is always drawn from the contact surface through the object and is perpendicular to the surface. In math books the direction perpendicular to the surface is known as the “normal” direction. The normal force, like tension, does not have a standard formula and is determined using the same method as in the previous lesson. **Consider the following ten examples. A 20 Kg block is used in every case. In some instances an applied force of 100 N is present. This applied force is due to a hand pushing on the block. Where necessary an angle of θ = 30° is used.**

A)



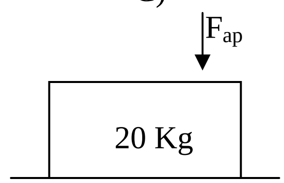
A 20 Kg block rests on a flat surface.

B)



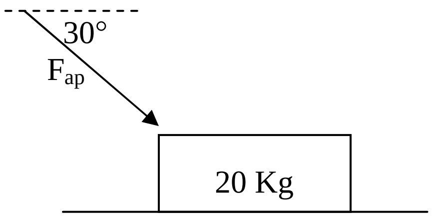
An applied force of 100N lifts up on the block.

C)



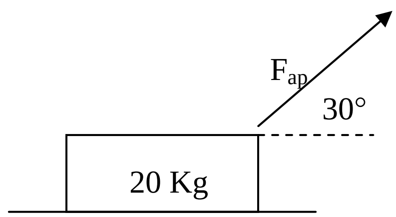
An applied force of 100N pushes down on the block.

D)



An applied force of 100 N acts at 30° below the horizontal. (Lawnmower & shopping cart)

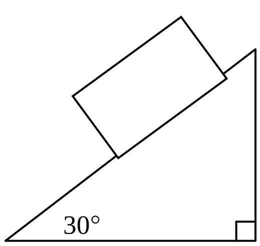
E)



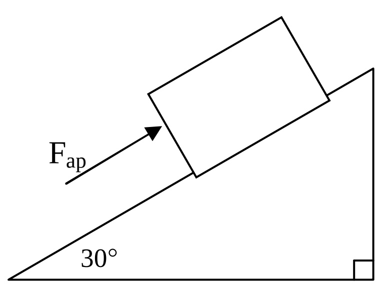
An applied force of 100 N acts at 30° above the horizontal. (Wagons & snow sleds)

The following five examples occur on a 30° inclined plane. Consider only forces ⊥ to the inclined surface. Don’t ask about the parallel forces until tomorrow!

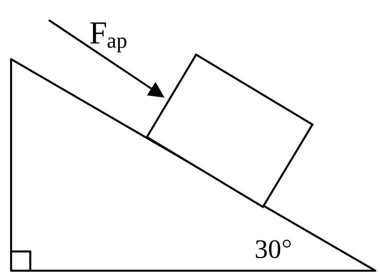
F)
A 20 Kg block rests on the incline.



G)
An applied force of 100 N pushes parallel & up the plane.



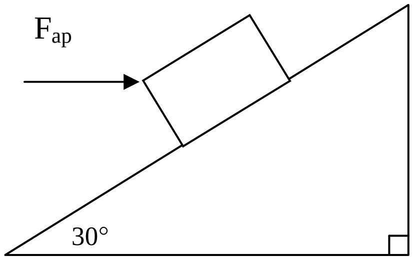
H)
An applied force of 100 N pushes parallel & down…

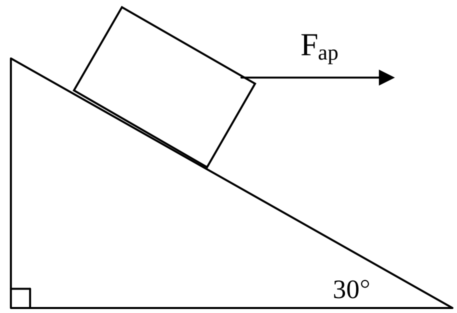


The previous two examples demonstrated applied forces that are parallel to the inclined plane. The next two examples have applied forces that are parallel to the ground.

I) An applied force of 100 N parallel to the ground pushes the block into the incline.

J) An applied force of 100 N parallel to the ground pulls the block away from the incline.





Answers

A) 200 N	B) 100 N	C) 300 N	D) 250 N	E) 150 N
F) 173 N	G) 173 N	H) 173 N	I) 223 N	J) 123 N

<u>Checkpoints for the previous two lessons:</u>

- ✓ Recognize that tension will be an appropriate force if cables, cords etc are involved.
- ✓ Use the conditions from Newton's 1st Law to determine the value for the tension in a system of strings if the mass is suspended at rest.
- ✓ Recognize that the normal force will be involved only if an object comes in contact with a surface and that the normal force is drawn from the surface through the object.
- ✓ Use the conditions from Newton's 1st Law to determine the value of the normal force on an object.
- ✓ Draw a *free-body* diagram incorporating weight, tension, applied forces and/or normal forces when appropriate.

Lesson 1-20 **Friction**

The force of friction is due to two surfaces interacting parallel to the surface rather than perpendicular to the surface. Friction occurs for two surfaces when the surfaces are at rest, when one surface is sliding over the other surface and when one surface is rolling over the other surface. These different situations are known as static friction, kinetic friction and rolling friction. Since rotational mechanics is not covered in this course we can dispense with the last form. The first two types of friction are similar. They are determined by the normal force and the roughness of the surfaces. To indicate the roughness of the surface requires a measurement of the *coefficient of friction*, μ. Mu ranges from 0 (frictionless) to 1 (very rough). In most instances the static measurement, μ_S, yields a value higher than the kinetic measurement, μ_K. You may have noticed that it is easier to keep something sliding than it is to get it started sliding.

<u>Static Friction</u>

$F_f \leq \mu_S n$

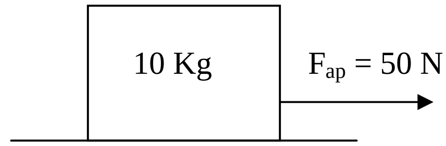
<u>Kinetic Friction</u>

$F_f = \mu_K n$

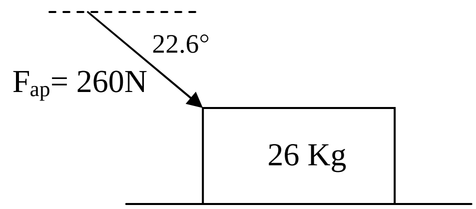
Except for lab we will ignore the "less than" condition for static friction.

$F_f = \mu n$ Practice Problems with Friction

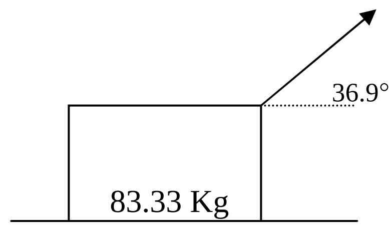
1. A 10 Kg box is placed on a level surface. A 50 N applied force acts horizontally on the box to move it at constant speed. Find the value for the normal force, the kinetic coefficient of friction and the force of friction acting on the box.



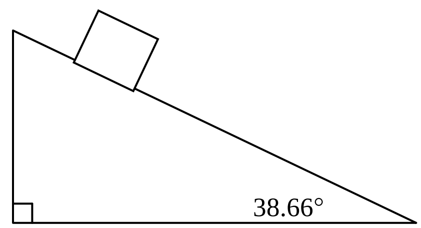
2. A 26 Kg block is placed on a level surface. An applied force of 260 N at 22.6° below the horizontal moves the block at constant speed. Find the normal force, the force of friction and the kinetic coefficient of friction.



3. An 83.33 kg crate is placed on a level surface. An applied force of 500 N at 36.9° above the horizontal moves the block at constant speed across the floor. Find the normal force, force of friction and the coefficient of friction.

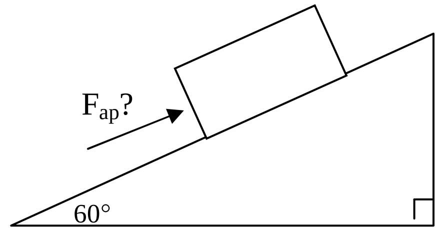


4. A 10 Kg box placed at the top of a 38.66° inclined plane slides slowly down the incline at constant speed. Find the normal force, the friction force and the coefficient of kinetic friction between box and incline.

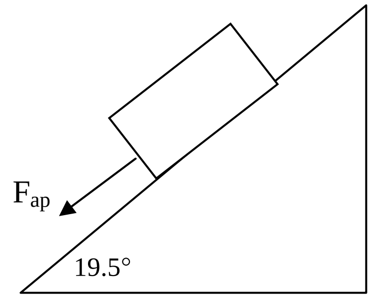


5. A 30 Kg block is placed at the bottom of a 60° incline. The coefficient of kinetic friction between block and incline is 5/6. How much force must be applied on the block parallel to the incline in order to move the block up the ramp at constant speed? First find the normal force and force of friction .

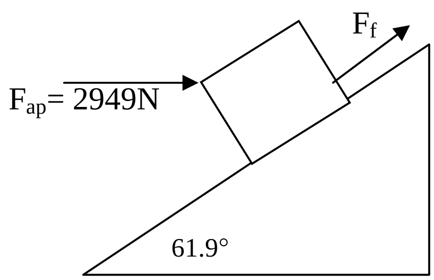
   n= _____ F_f = ______ F_{ap}= ______



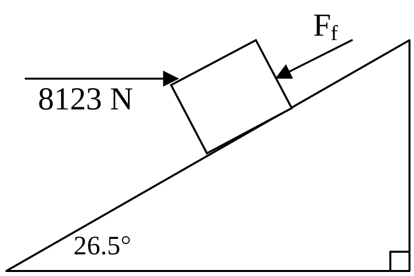
6. A force F_{ap} is used to move a 42 Kg crate down a 19.5° incline at constant speed. The applied force acts parallel to the incline and down the ramp. The coefficient of friction is 6/7. Find the normal force, the force of friction and the applied force needed to move the crate down at constant speed.



7. A 595 Kg block is placed at the top of a 61.9° ramp. A force of 2949 N pushes on the block parallel to the ground and into the ramp. This allows the block to slide down the incline at constant speed. Find the normal force, force of friction and the coefficient of friction between block and surface.



8. A 4654 N object is moved up a 26.5° inclined plane at constant speed by means of a horizontal applied force of 8123 N. Find the normal force, the force of friction and the coefficient of friction between object and surface.



Answers

1	100 N	50 N	1/2
2	360 N	240 N	2/3
3	533 N	400 N	3/4
4	78.1 N	62.5 N	4/5
5	150 N	125 N	385 N
6	396 N	339 N	199 N
7	5404N	3860 N	5/7
8	7789N	5192 N	2/3

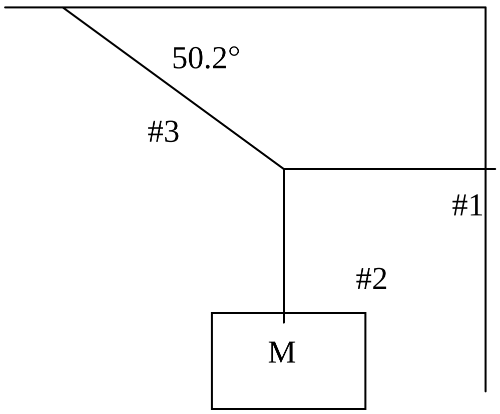
Final Checkpoints

- ✓ Describe the relationship among friction forces, normal forces and mu.
- ✓ Compare and contrast the static and kinetic coefficients of friction.
- ✓ Compare and contrast the static and kinetic forces of friction.
- ✓ Draw a free-body diagram including the force of friction.
- ✓ Use Newton's 1st Law to calculate force with friction.

Physics Practice Test 104 A   Name ___________________________

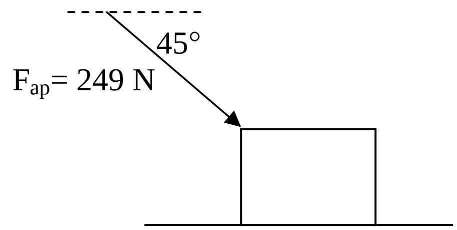
Use g= -10 m/s^2

A 6 Kg object is hung as shown in the diagram below. The string labeled as #3 forms a 50.2° angle with the horizontal.



1. The tension in line #1 is ___ N.
   a) 50
   b) 60
   c) 70
   d) 80
   e) 90
2. The tension in line #2 is ___ N.
   a) 30
   b) 40
   c) 50
   d) 60
   e) 70
3. The tension in line #3 is ___ N.
   a) 67.5
   b) 78.1
   c) 89.4
   d) 94.9
   e) 106.3

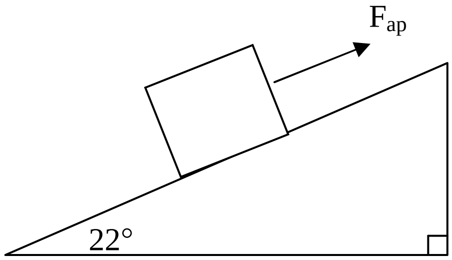
A 6.8 Kg block is placed on a level surface. An applied force of 249 N at 45° below the horizontal moves the block at constant speed.



4. The coefficient of kinetic friction is
   a) 0.16
   b) 0.30
   c) 0.44
   d) 0.58
   e) 0.72
5. The normal force is ___N.
   a) 164
   b) 204
   c) 244
   d) 284
   e) 324
6. The force of friction is ____N.
   a) 35.8
   b) 61.2
   c) 95.1
   d) 125
   e) 176
7. To move the block sideways at constant speed over the <u>same surface</u> requires a horizontal applied force of ___ Newtons.
   a) 25
   b) 32
   c) 40
   d) 49
   e) 59

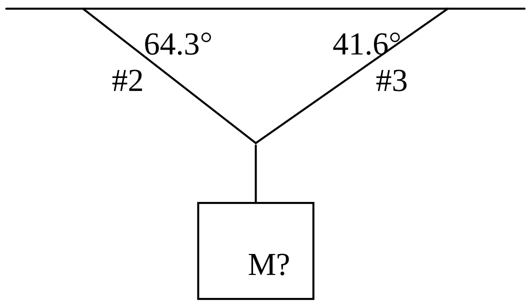
Test 104A (continued)

A 24 kg block is placed on a 22° inclined plane. A 219 N applied force parallel to the surface of the incline moves the block up at constant speed.



8. The normal force acting on the block is ___ N.
   a) 90.1
   b) 125.9
   c) 206.3
   d) 222.5
   e) 448.0
9. The coefficient of friction between block and incline is ___.
   a) 0.23
   b) 0.42
   c) 0.58
   d) 0.70
   e) 0.85
10. The force of friction is ___ N.
   a) 63.1
   b) 107.1
   c) 129.1
   d) 175.4
   e) 188.2
11. To move the block down the incline at constant speed would require a force of ___ N parallel to the incline.
   a) 13.2
   b) 25.5
   c) 39.2
   d) 52.6
   e) 68.2

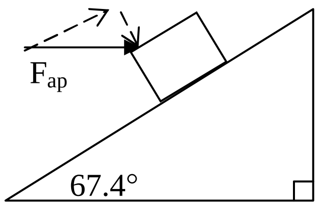
An unknown mass is hanging in the figure below. The tension in cable #3 is 361.2N. Cable #3 forms an angle of 41.6° with the horizontal. Cable #2 forms an angle of 64.3° with the horizontal.



12. The unknown mass is ___ Kg.
   a) 50 d) 80
   b) 60 e) 90
   c) 70
13. The tension in cable #2 is ___ N.
   a) 241
   b) 354
   c) 469
   d) 506
   e) 622
14. The horizontal component of the tension in cable #3 is ___ N.
   a) 180
   b) 210
   c) 240
   d) 270
   e) 300
15. The vertical part of the tension in cable #3 is ___ N.
   a) 140 d) 440
   b) 240 e) 540
   c) 340
16. Tension in the vertical cable is ___N.
   a) 500
   b) 600
   c) 700
   d) 800
   e) 900

Test 104 A (continued)

A 26 kg box is lowered from the top of an inclined plane. The incline has been raised 67.4° from the horizontal. An applied force of 173.3 N parallel to the ground and toward the incline acts to lower the box at constant speed.



17. The force of friction acting on the block is about ___ N.
    a) 100
    b) 148
    c) 173
    d) 182
    e) 190
18. The normal force acting on the block is about ___N.
    a) 200
    b) 220
    c) 240
    d) 260
    e) 280
19. The part of the applied force parallel to the incline is ___ N.
    a) 50
    b) 58
    c) 60
    d) 67
    e) 96
20. The kinetic coefficient of friction is
    a) 0.37
    b) 0.50
    c) 0.67
    d) 0.76
    e) 0.86

<u>Answers</u>

1. A
2. D
3. B
4. E
5. C
6. E
7. D
8. D
9. C
10. C
11. C
12. D
13. E
14. D
15. B
16. D
17. C
18. D
19. D
20. C