

Introduction to Statics

.PDF Edition – Version 0.95

Unit 14

Free Body Diagrams of Single-Body Systems

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Unit 14

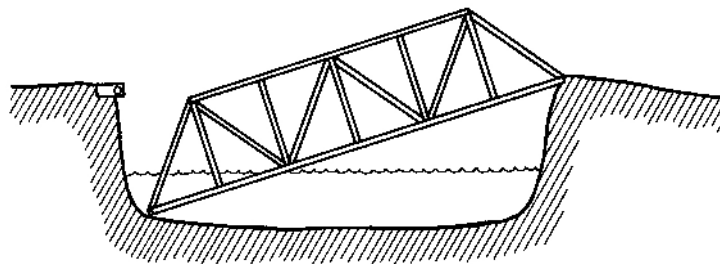
Free Body Diagrams of Single-Body Systems

Frame 14-1

Introduction

In this unit you will learn to draw and use "free body diagrams". This operation is quite simple in many problems, so simple, in fact, that it is skipped as an "extra" step by some beginners in mechanics, to their later embarrassment. Those more experienced in the subtle pitfalls of mechanics problems consider this the magical step which assures them that they have included everything in its proper place.

It's our hope that this unit will keep you from being the engineer who (only?) forgot one bolt.



Correct response to preceding frame

No response

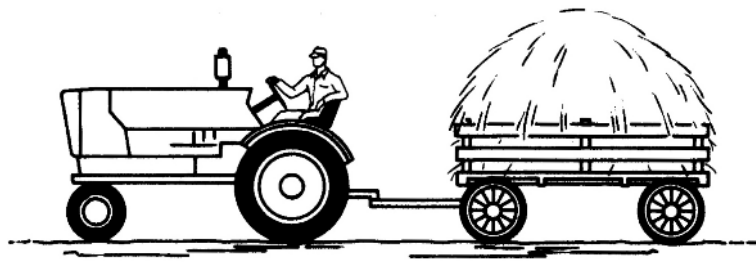
Frame 14-2

Systems

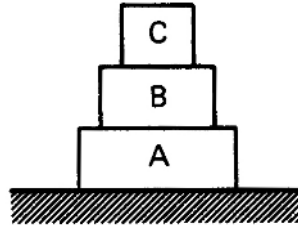
When we speak of a *free body diagram* (FBD) we refer to the FBD of a system. A "system" may consist of one object, several objects, or only a part of an object, depending on what forces or motions we wish to study.

On the drawings below circle the system which consists of

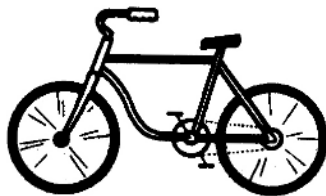
1. the tractor



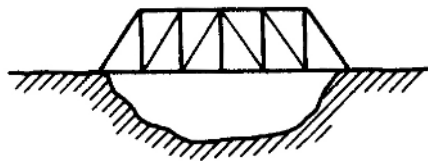
2. blocks A and B



3. the front tire on the bicycle



4. the bridge

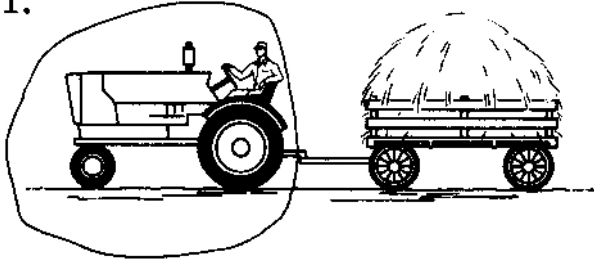


5. Is a system always complicated? Yes No

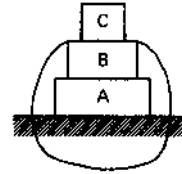
6. May a system be complicated? Yes No

Correct response to preceding frame

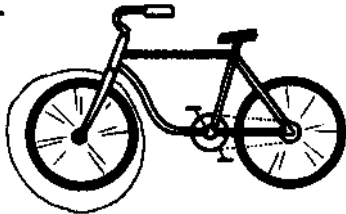
1.



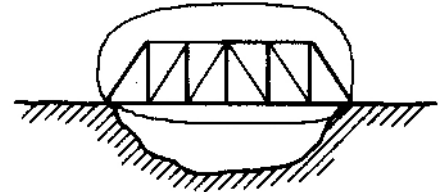
2.



3.



4.



5. No, they are not always complicated.

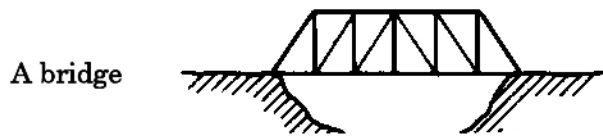
6. Yes, it may be complicated.

Frame 14-3

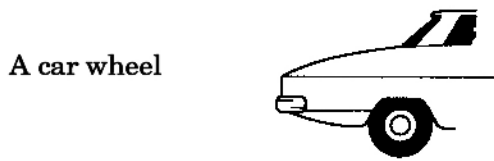
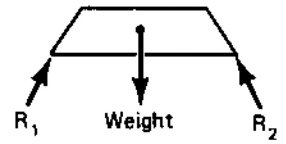
Sketches

Our first job in solving a mechanics problem will be to (1) make a simple sketch of the system, (2) show the external forces on it. The purpose of our sketch is to show the location of the forces exerted on the system by external objects.

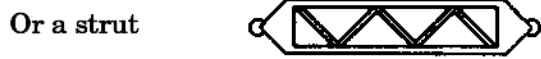
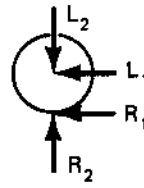
For example:



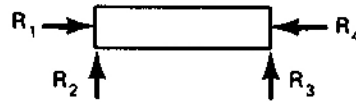
might be shown like this



might appear as



as



1. Is it necessary to draw all details to scale?

Yes

No

2. Is it helpful to show the background of the system?

Yes

No

3. Should things have shapes which approximate their actual configurations?

Yes

No

Correct response to preceding frame

1. No
 2. No. It helps to clarify the drawing when we leave out detail of all sorts.
 3. Yes. It's hard to see very simple relationships when wheels are drawn as squares and box cars as spheres.
-

Frame 14-4

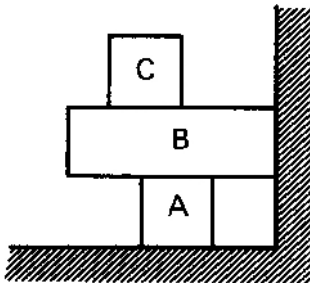
Sketches

Make sketches of the following systems (do not put forces in yet).

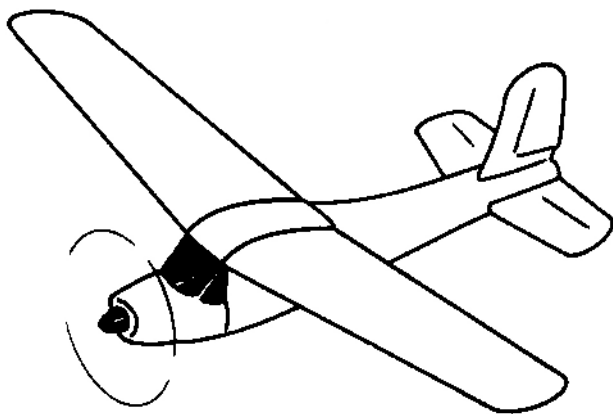
1. A black box

2. A ball

3. A system consisting of blocks A and B shown in this drawing



4. One wing of this airplane



Correct response to preceding frame

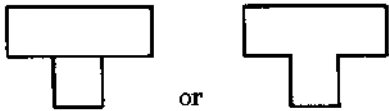
1.



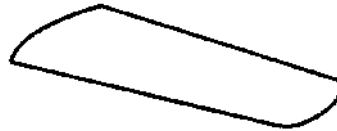
2.



3.



4.



or perhaps  or 

or 

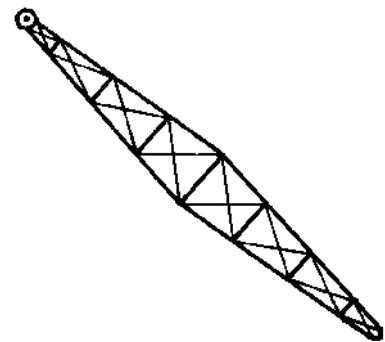
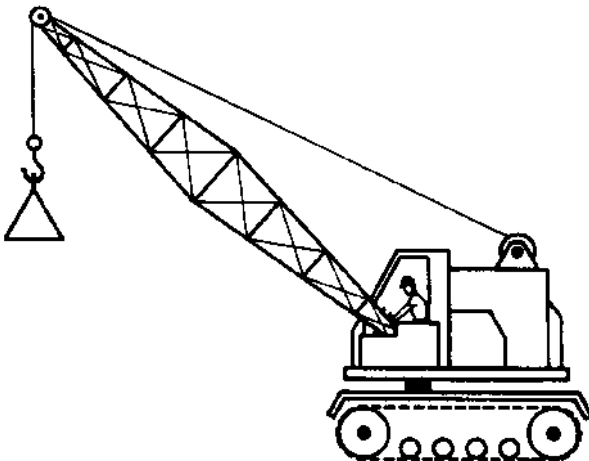
depending on what forces you are going to show later

Frame 14-5

Location of Forces

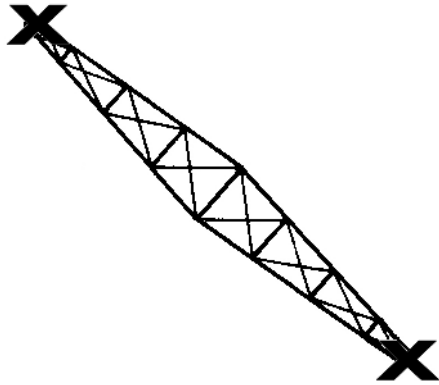
Once we have made our simple sketch we will proceed to show all the external forces which act on our system in their proper places.

Mark an X on the picture below at each point where you would expect a force on the boom of the crane.



(This part is the boom.)

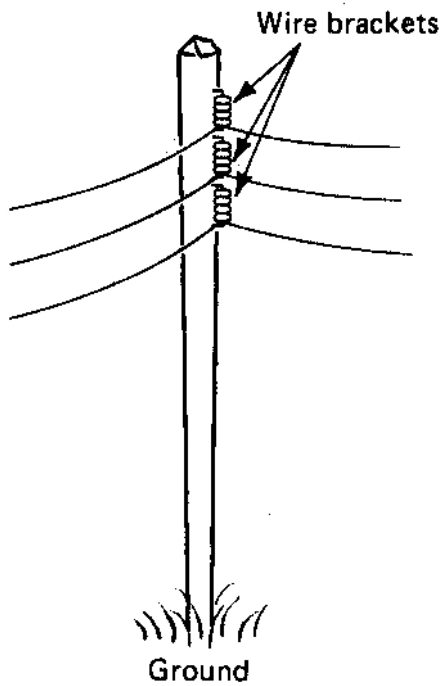
Correct response to preceding frame



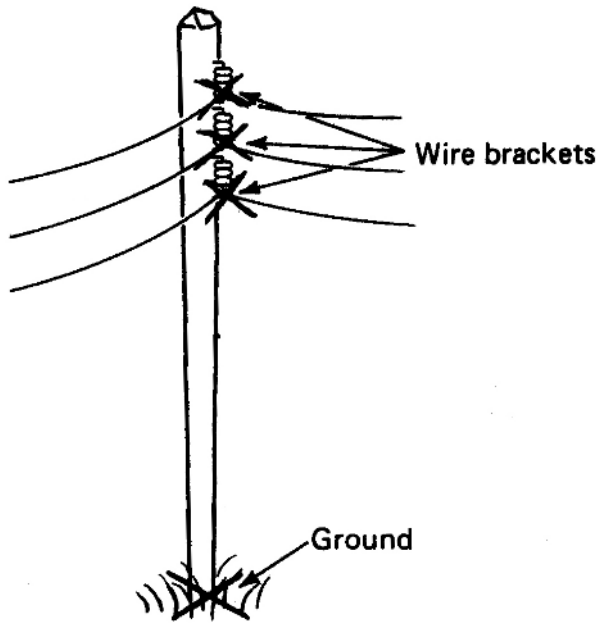
Frame 14-6

Location of Forces

Mark an X on the drawing of an electric power pole where you would expect forces to be applied to it.



Correct response to preceding frame



Frame 14-7

Location of Forces

When you draw a free body diagram, you should expect to put in a force at ***each point*** where the system makes contact with something outside the system.

True False

When you draw a free body diagram you should put in forces ***only*** at points where the system touches something outside the system.

True False

Correct response to preceding frame

True

False, some forces, such as weight, don't need a "touch" point.

Frame 14-8

Forces on FBD

One force which should be considered* in all everyday problems is the force exerted on the body by the earth. The force which results from the gravitational attraction

between the earth and the body is called the _____ of the body.

* (Often after considering it we call it negligible)

Correct response to preceding frame

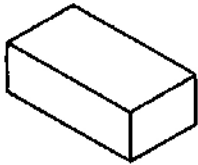
the **weight** of the body (Not gravity. You don't say "My gravity is 140 pounds.")

Frame 14-9

Weight

We often consider the weight of a body as if it were concentrated at a single point. Show the weight approximately where you would expect it to act on the bodies shown below and label it W.

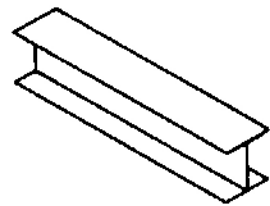
(a)



(b)



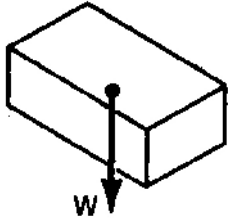
(c)



The point of application of this force is called the center of _____ .

Correct response to preceding frame

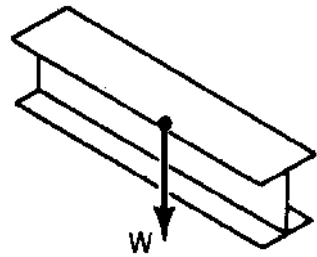
(a)



(b)



(c)



mass (or center of gravity)

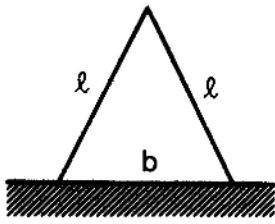
Frame 14-10

Center of Mass

For plane figures (bodies of uniform thickness) the center of mass coincides with the centroid of the area.

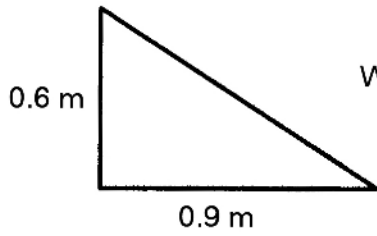
Show the weight at the proper location on the following plane figures. (Give dimensions.)

1.



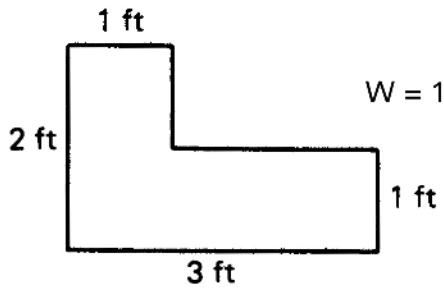
$W = 7$ pounds

2.



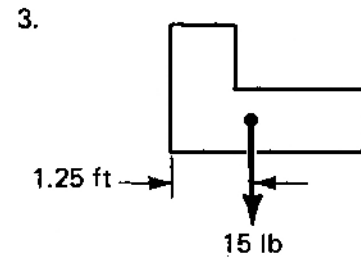
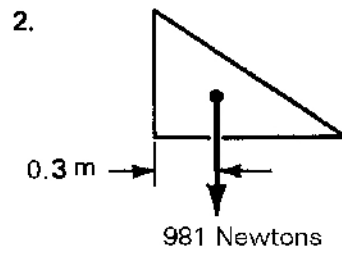
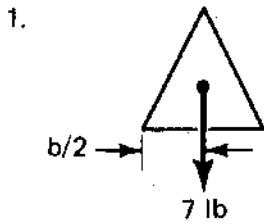
$W = 100$ kilograms

3.



$W = 15$ pounds

Correct response to preceding frame



The vertical dimension to the center of mass is not needed as we only want the line of action of the weight.

Frame 14-11

Transition

Now you're able to show weight on free bodies.

UNIT 14 SCOREBOARD

- Sketches
- Weight
- Ropes, chains, and cables
- Frictionless surfaces
- Roller supports
- Pin joints

Turn to the next frame.

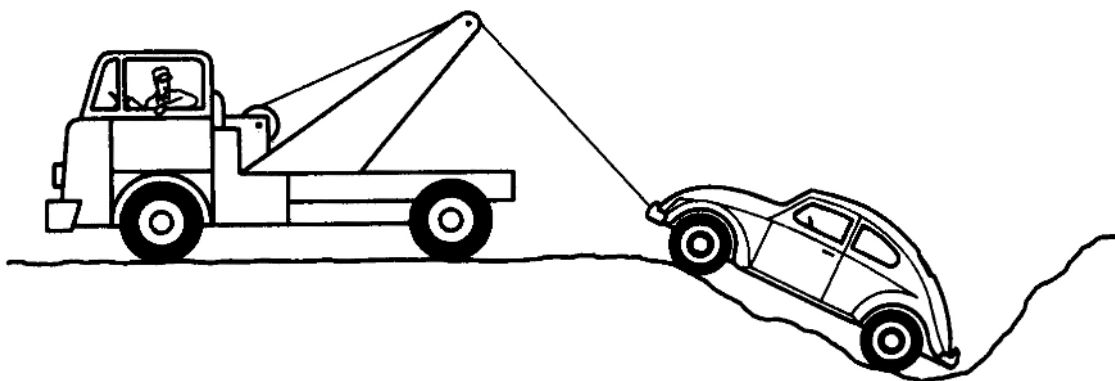
Correct response to preceding frame

No response

Frame 14-12

Ropes, Chains and Cables

One very common way of transmitting forces from one body to another is by means of ropes, chains or cables. In the illustration below the crew with the wrecker is attempting to haul a car out of a ditch.



1. Can the cable pull the car toward the left?

Yes

No

2. Can the cable push the car toward the right?

Yes

No

Correct response to preceding frame

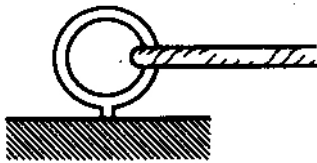
1. Yes
 2. No
-

Frame 14-13

Ropes, Chains and Cables

In the two cases below give the components of the force which the rope applies to the ring if the tension in the rope is 100 pounds:

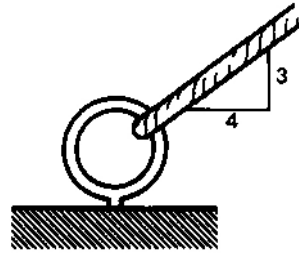
1.



$$F_x = \underline{\hspace{4cm}}$$

$$F_y = \underline{\hspace{4cm}}$$

2.



$$F_x = \underline{\hspace{4cm}}$$

$$F_y = \underline{\hspace{4cm}}$$

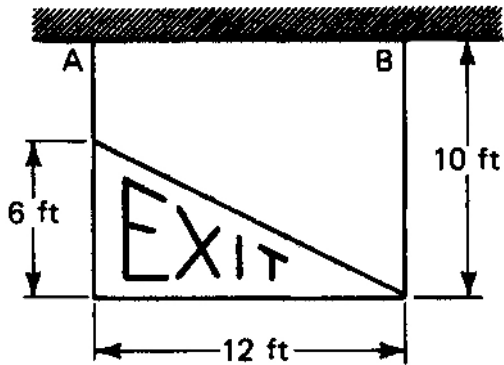
3. What is the direction of a force applied with a rope? _____

Correct response to preceding frame

1. $F_x = 100 \text{ lb}$ $F_y = 0 \text{ lb}$
 2. $F_x = 80 \text{ lb}$ $F_y = 60 \text{ lb}$
 3. Along the rope
-

Frame 14-14

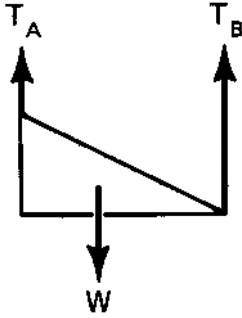
Ropes and Weight



Draw a free body diagram of the sign showing the weight and denoting the tension in the cable A as T_A and the tension in cable B as T_B .

(Make a separate sketch and show only the sign and the forces acting on it.)

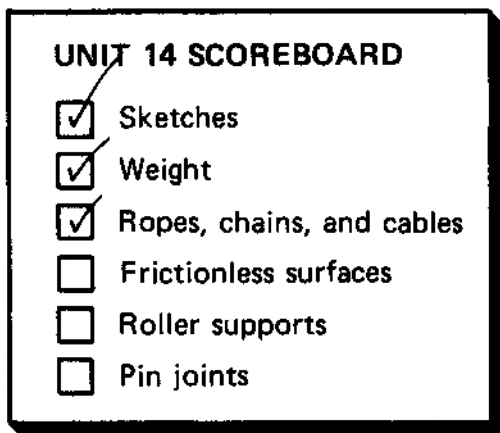
Correct response to preceding frame



Frame 14-15

Transition

The next section will introduce something which does not exist ... a "frictionless" surface.



This is a rather slippery topic -- useful, but impossible.

Turn the page.

Correct response to preceding frame

No response

Frame 14-16

Frictionless Surfaces

Many problems involve bodies which rest against very slippery surfaces which we idealize as "smooth" or "frictionless."

Suppose you had a box which was at rest on an ice skating rink.



1. Can the ice exert a normal force such as the one labeled N on the box?

Yes No

2. Can the ice exert a force in the opposite direction to N?

Yes No

3. Can the ice exert a tangential (sideways) force such as the one labeled T?

Yes No

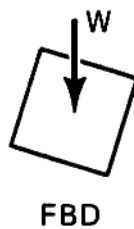
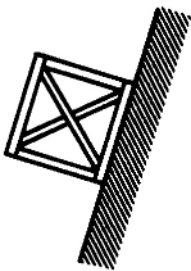
Correct response to preceding frame

1. Yes, of course, otherwise the box would fall through the ice.
 2. No, such a force would imply a suction.
 3. No, ice can't push sideways unless you cut into it.
-

Frame 14-17

Frictionless Surfaces

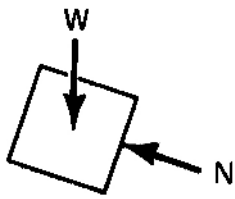
Suppose our smooth surface was nearly vertical.



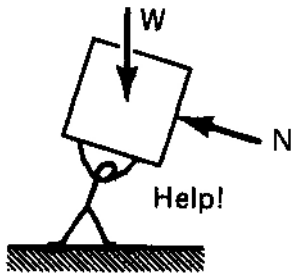
1. Can the wall push the box toward the left?
If so, draw this force on the incomplete FBD. Yes No
2. Can the wall pull the box toward the right?
If so, draw this force on the FBD. Yes No
3. Can the (frictionless) wall hold the box up?
If so, draw this lifting force on the FBD. Yes No

Correct response to preceding frame

1. Yes
2. No
3. No



This isn't in static equilibrium.

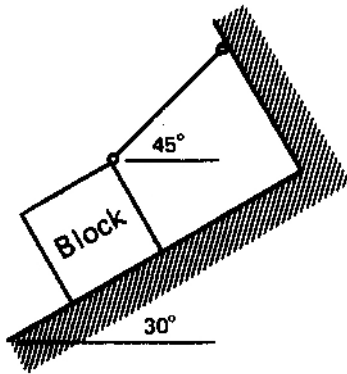


We would need to add a prop to hold it if we wanted it to stay where it is.

Frame 14-18

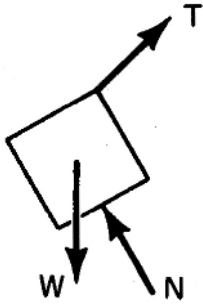
Frictionless Surfaces

A block rests on an inclined smooth surface and is held in equilibrium with a rope.



Draw a free body diagram of the block.

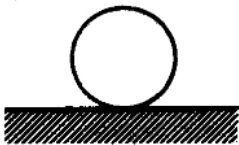
Correct response to preceding frame



Frame 14-19

Frictionless Surfaces

Often, when a body rests on a smooth surface, only one of the surfaces is flat. For instance consider a ball on a table.



1. Is a force normal to the surface of the ball possible?



Yes No

2. Is a force tangent to the surface of the ball possible?



Yes No

Correct response to preceding frame

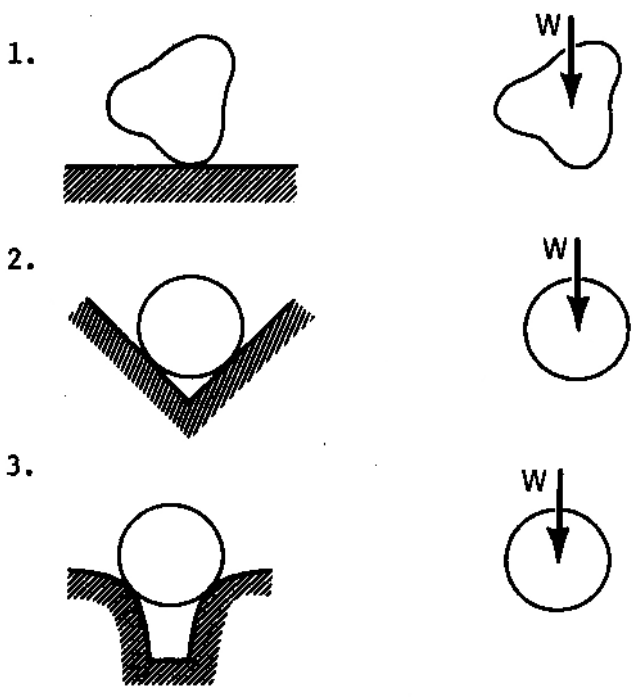
1. Yes
 2. No
-

Frame 14-20

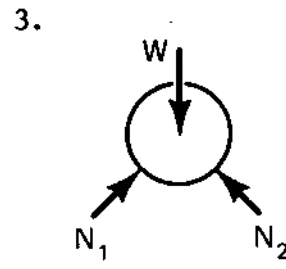
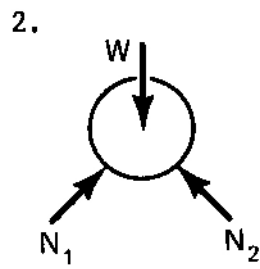
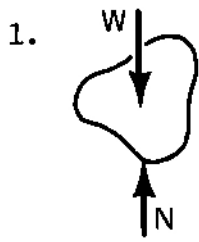
Frictionless Surfaces

Rule: *When two frictionless surfaces are in contact with one another the contact forces are normal to the tangent at the point of contact.*

Draw the contact forces on the following FBDs.



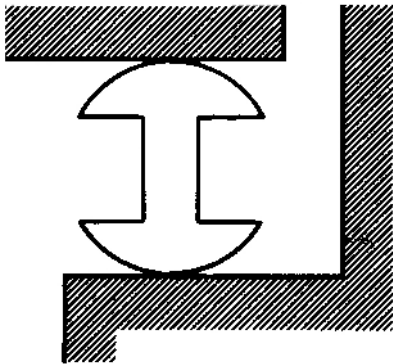
Correct response to preceding frame



Frame 14-21

Transition

Often bridges are placed on a form of roller to permit free movement as the bridge expands and contracts due to heat. Perhaps you have noticed supports like this.



The next section will give you some information on various sorts of rollers.

(Go to the next frame. No response is necessary.)

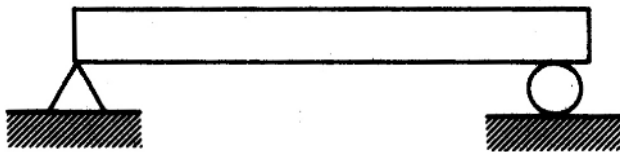
Correct response to preceding frame

No response

Frame 14-22

Roller Supports

Often we will show a system which has one or more points which are supported on rollers.



1. Will the support at the right hand end of this system hold a load which is normal to the ground surface?

Yes No

2. Will the support resist a load which is tangent to the surface?

Yes No

Correct response to preceding frame

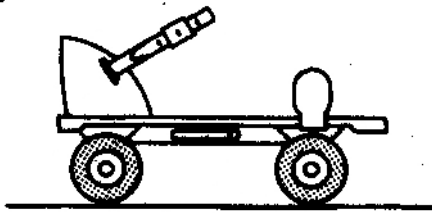
- 1. Yes
 - 2. No
-

Frame 14-23

Roller Supports

In order to work properly a roller must be placed on a hard, smooth surface.

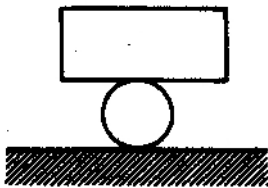
1.



Is this a usable roller support?

Yes No

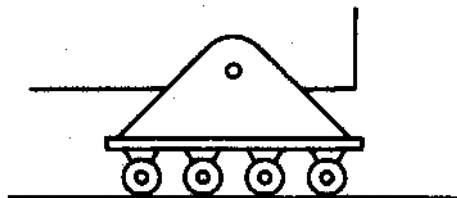
2.



How about this?

Yes No

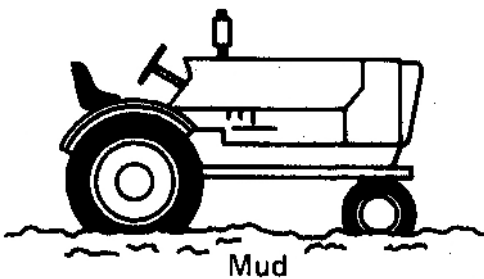
3.



And this?

Yes No

4.



This?

Yes No

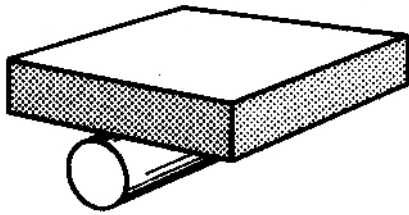
Correct response to preceding frame

- 1, 2, 3. Yes
 4. No, the mud will resist lateral loads.
-

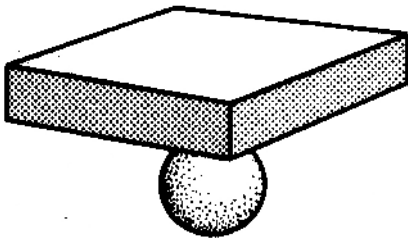
Frame 14-24

Sidelight

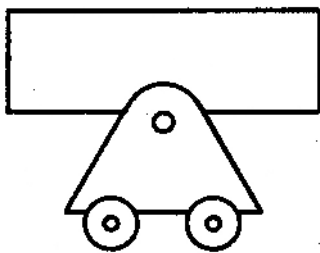
In general, the people who devise mechanics problems will use



cylindrical rollers,



spherical rollers,



or small dollies interchangeably. They are all roller supports.

The drawing of roller supports is one of the few places where "artistic license" is permitted in mechanics.

On to the next frame.

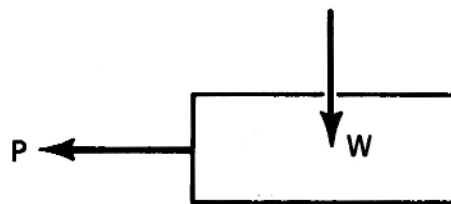
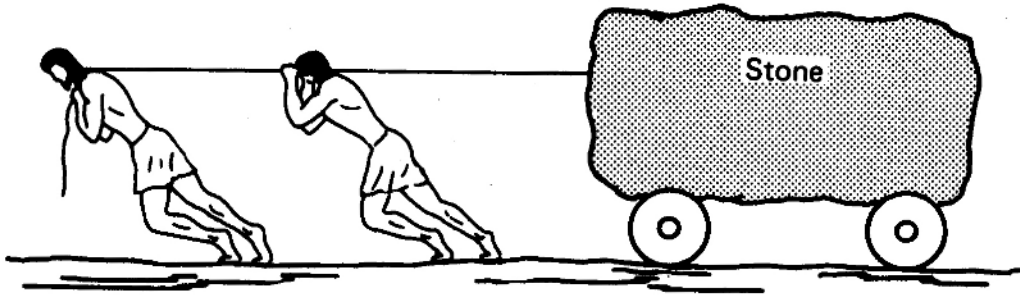
Correct response to preceding frame

No response

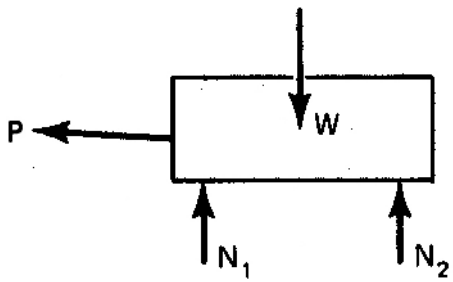
Frame 14-25

Roller Supports

Complete the FBD of the large stone.



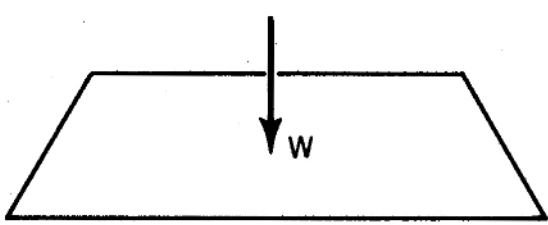
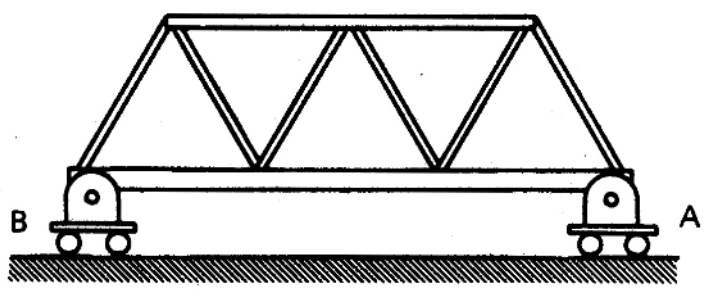
Correct response to preceding frame



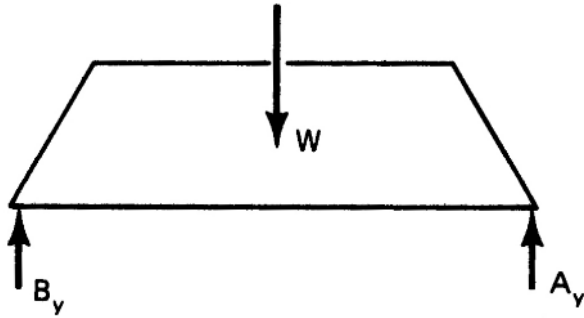
Frame 14-26

Roller Supports

Complete the FBD of the following system.



Correct response to preceding frame



Frame 14-27

Evaluating Free Body Diagrams

If I were grading your FBDs on a test, I would use a scale something like this:

25% - Separate and clear sketch

25% - All forces shown

25% - All forces in correct directions (The sense may not be known)

25% - Forces clearly labeled

Go back and grade your work on the last two FBDs.

Correct response to preceding frame

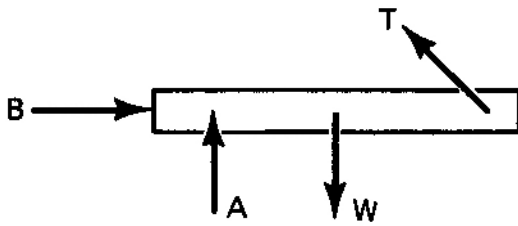
100% on each problem

Frame 14-28

Problem

Complete Page 14-1 in your notebook.

Correct response to preceding frame



Frame 14-29

Transition

Another very common occurrence in mechanical constructions is the connector which is known as the pin-joint, hinge, or pivot.

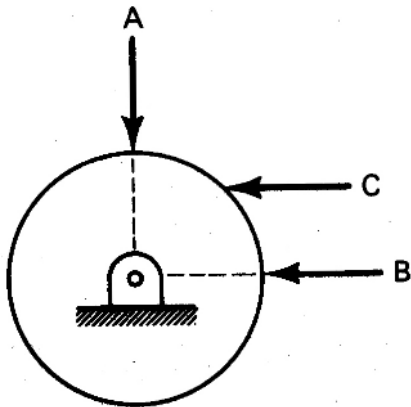
Go to the next frame.

Correct response to preceding frame

No response

Frame 14-30

Pin Joints



The disc is supported by a frictionless pin through its center.

1. Will the disc be in equilibrium under load A alone? Yes No
2. Will it be in equilibrium under load B alone? Yes No
3. Will it be in equilibrium under load C alone? Yes No
4. Will it be in equilibrium under simultaneous loads A and B? Yes No
5. Which forces have zero moment about the center? _____
6. The lines of action of A and B both _____

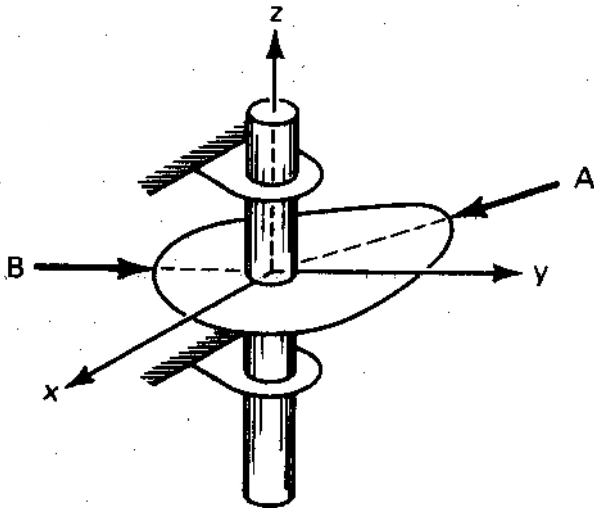
Correct response to preceding frame

1. Yes
 2. Yes
 3. No, it will turn
 4. Yes
 5. A and B have zero moment
 6. pass through the center (Or equivalent response)
-

Frame 14-31

Pin Joints

A pin joint will transmit forces which are directed to pass through the center of the pin and which are directed perpendicular to the axis of the pin.



1. Can the pin carry load A? Yes No
2. Can the pin carry load B? Yes No

Correct response to preceding frame

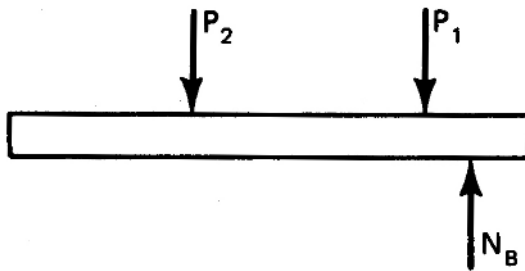
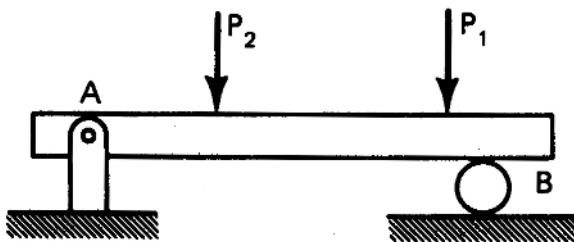
Yes

Yes

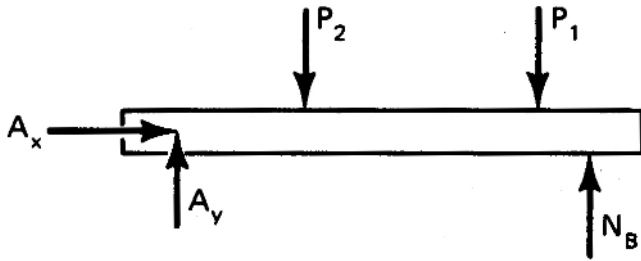
Frame 14-32

Pin Joints

Complete the free body diagram of the beam, representing the force A as components in the x and y directions. Neglect the weight of the beam.



Correct response to preceding frame



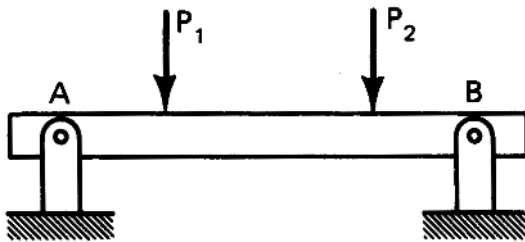
Frame 14-33

Pin Joints

Note that in the response to the preceding frame a component at the pin in the x direction is shown even though we might easily guess that $A_x = 0$.

It is a good practice to include all forces until "proven" negligible.

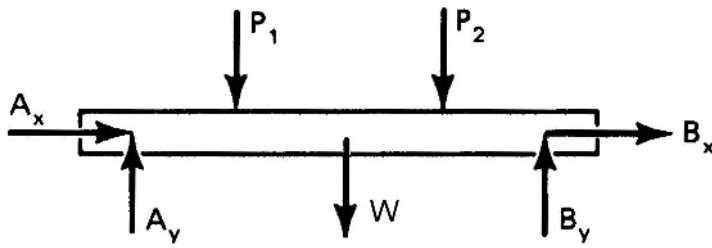
1. Draw a FBD of the beam below



2. $A_x = 0$? Yes No Don't know

Correct response to preceding frame

1.



(Or equivalent response)

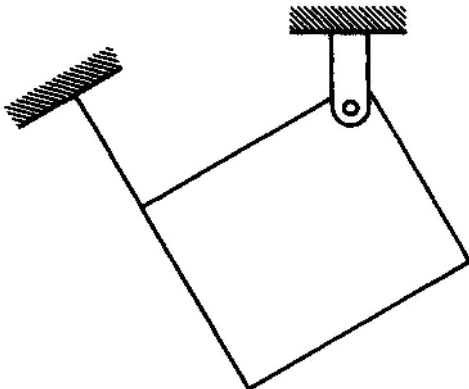
2. We don't know. A_x is not zero unless B_x is also zero.

Frame 14-34

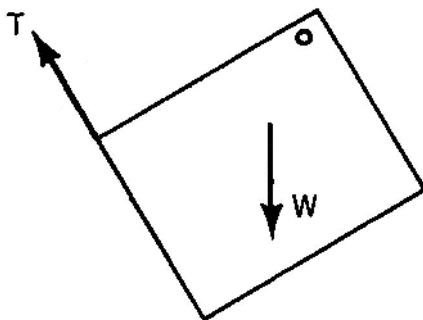
Pin Joints

Complete the diagram below

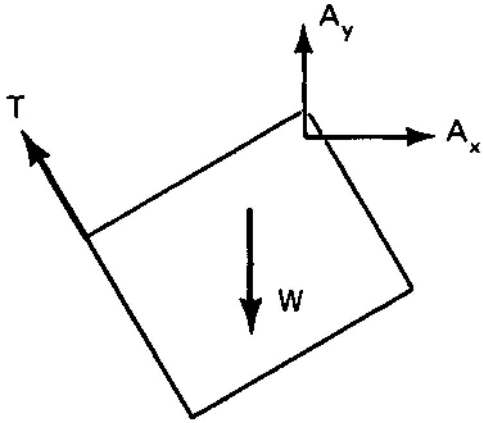
Picture



Free Body Diagram



Correct response to preceding frame

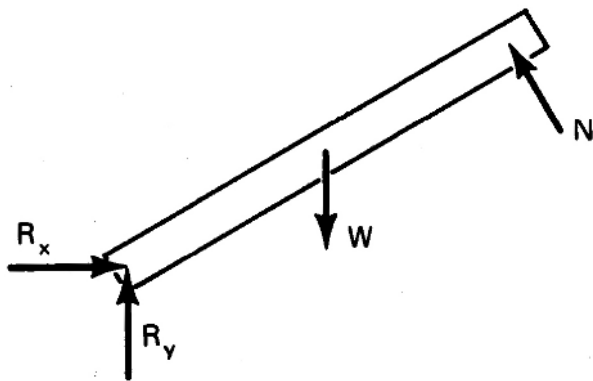


Frame 14-35

Problem

Work problem 14-2 in your notebook.

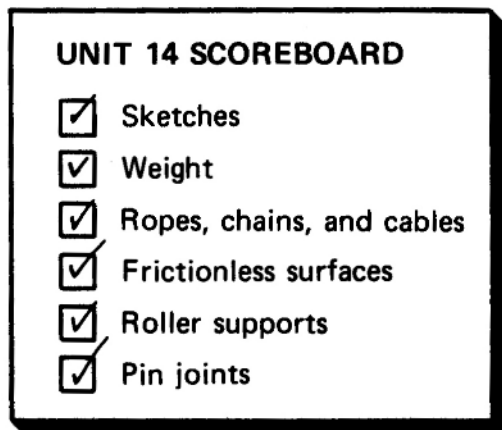
Correct response to preceding frame



Frame 14-36

Closure

For those of you fans who keep scorecards here's a summary of events through the 37th frame.



You now should know how to draw free body diagrams of single bodies. We will consider FBDs of systems of several bodies in the unit after next.

In the mechanics problems which you have to work in this and other courses you should always start a solution with a correct FBD and then you should be able to use it as a "check-list" as you write the necessary equations for the system. The whole business isn't very complicated for most problems, and it speeds up the work on the remainder of the problem.