NUS
National University of Singapore

ME2115/ME2115E/TME2115 -

Mechanics of Machines

Review of free-body diagram

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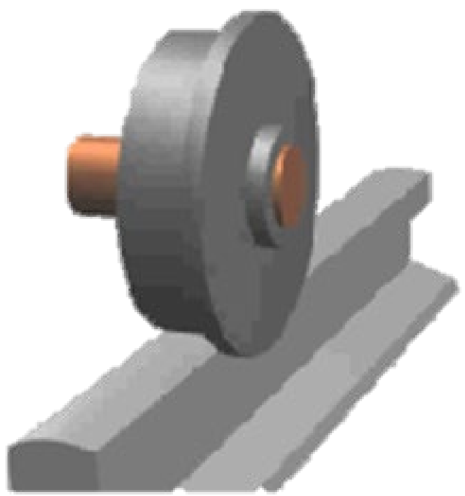
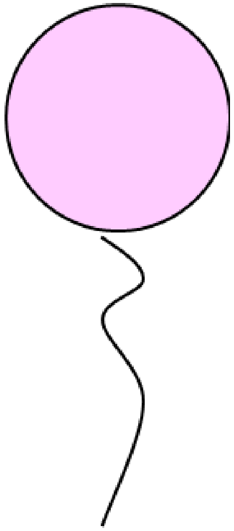
Review of F. B. D

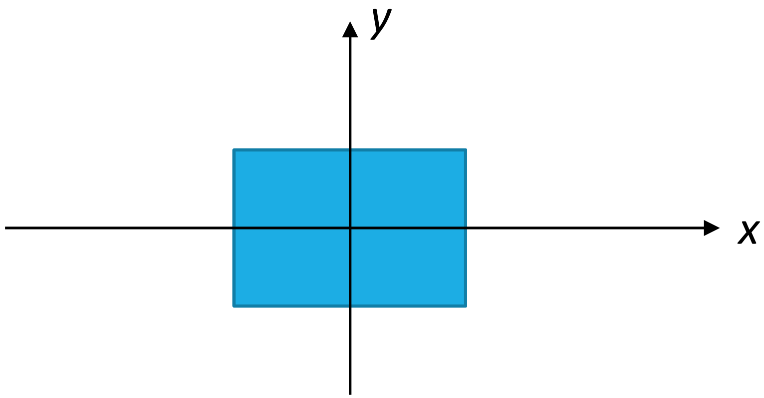
Free body vs. constrained body



Constrained body



Free body
No constraint

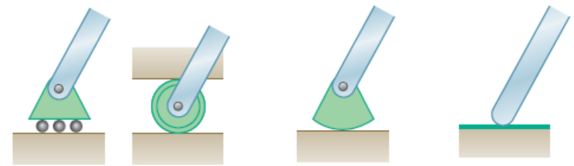
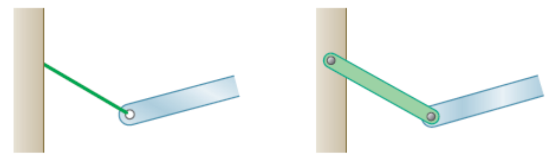
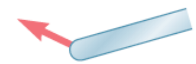
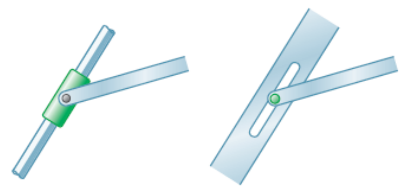
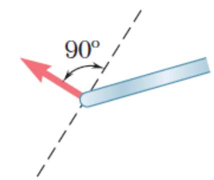
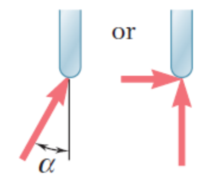
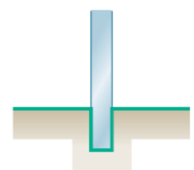
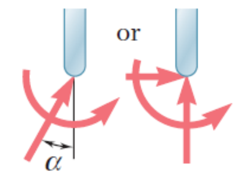


In a 3D space, a free body has 6 degrees of freedom: translation along *x, y, z*; rotation about *x, y, z*.
However, in a 2D plane, a free body only has 3 degrees of freedom: translation along *x*, *y*; rotation about *z*. WHY?

Will move out of the plane if rotates about *x* or *y*.

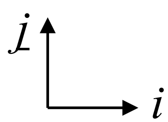
Reactions at Supports and Connections for a two-dimensional structure

Must remember!

Support or Connection	Reaction	Number of Unknowns
 Rollers; Rocker; Frictionless surface	 Force with known line of action	1
 Short cable; Short link	 Force with known line of action	1
 Collar on frictionless rod; Frictionless pin in slot	 Force with known line of action	1
 Frictionless pin or hinge; Rough surface	 Force of unknown direction	2
 Fixed support	 Force and couple	3

The first step in the solution of any mechanical problem concerning the equilibrium of a rigid body is to construct an appropriate free-body diagram of the body.

Without a proper F.B.D, one will construct wrong equations accordingly and then wrong answers.

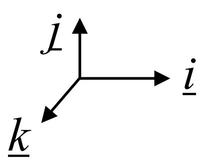


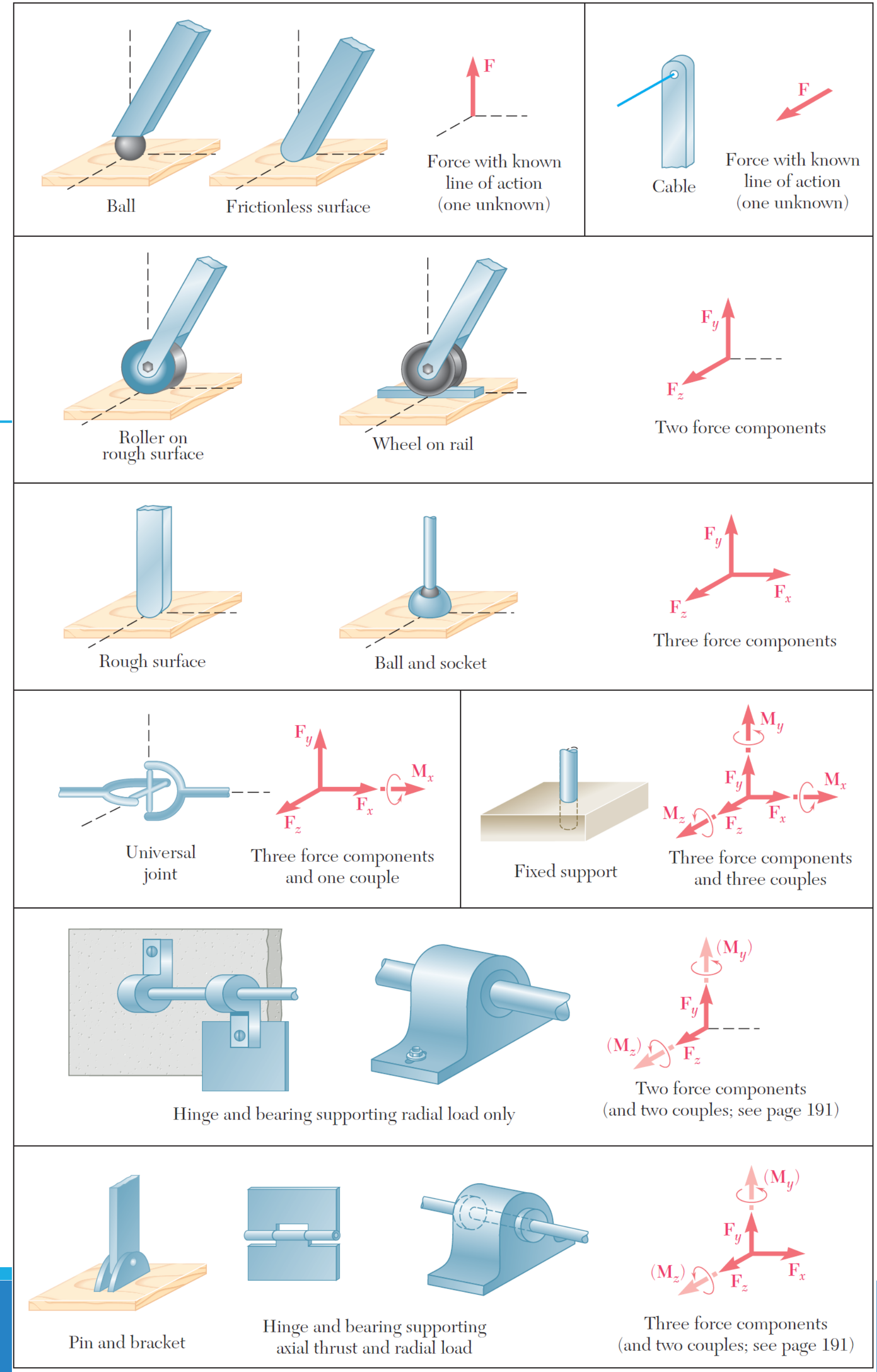
Reactions at Supports and Connections for a three-dimensional structure

Must remember!

It is necessary to show on the diagram the reactions through which the ground and other bodies oppose a possible motion of the body.

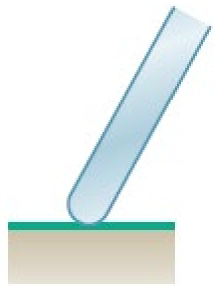
In summary, if a support prevents translation of a body in a particular direction, then the support exerts a constrained force on the body in that direction. If a rotation is prevented, then the support exerts a moment on the body.



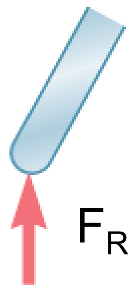


Typical supports and connections

Surface support

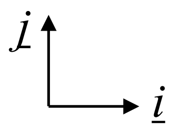


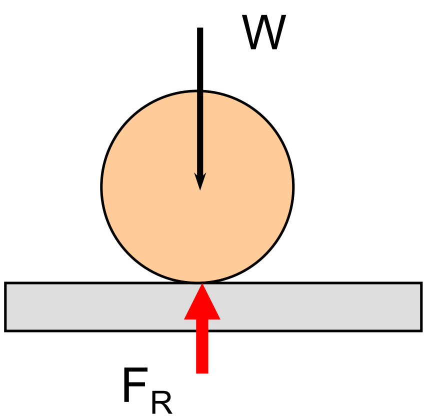
Frictionless surface

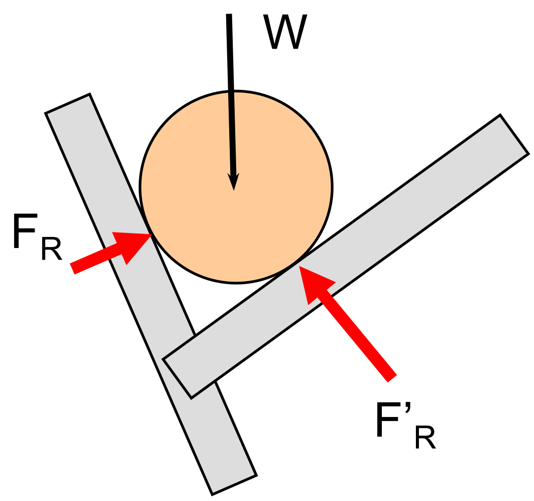


Force with known line of action

Constrained force, F_R
Direction normal to the surface at the contact point





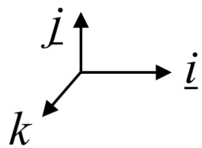


Review of F. B. D

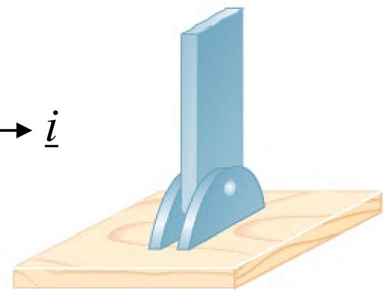
Pin/pin and bracket/roller supports

2D structure

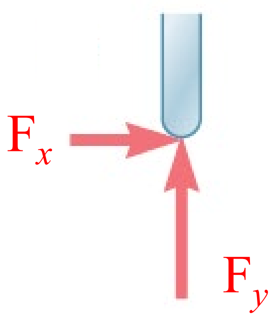
Frictionless pin

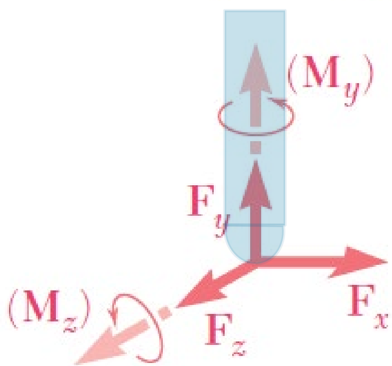


3D structure

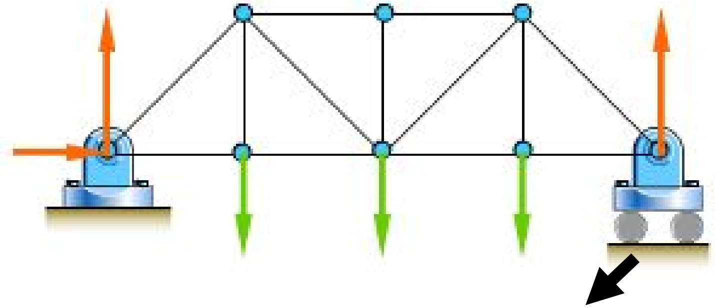


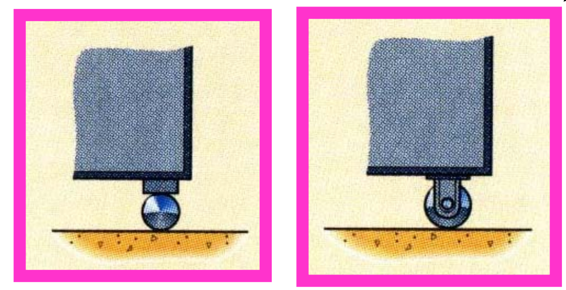
Pin and bracket



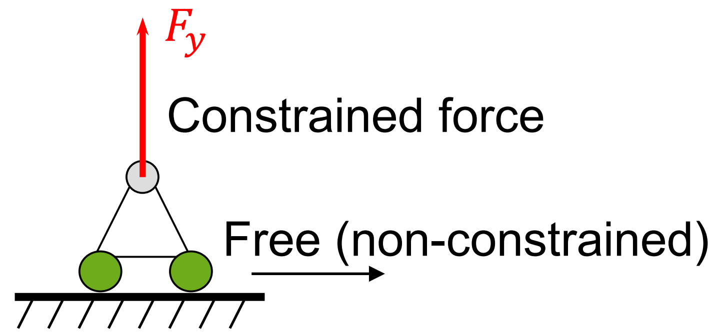


2D structure





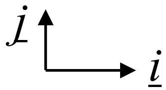
Roller support

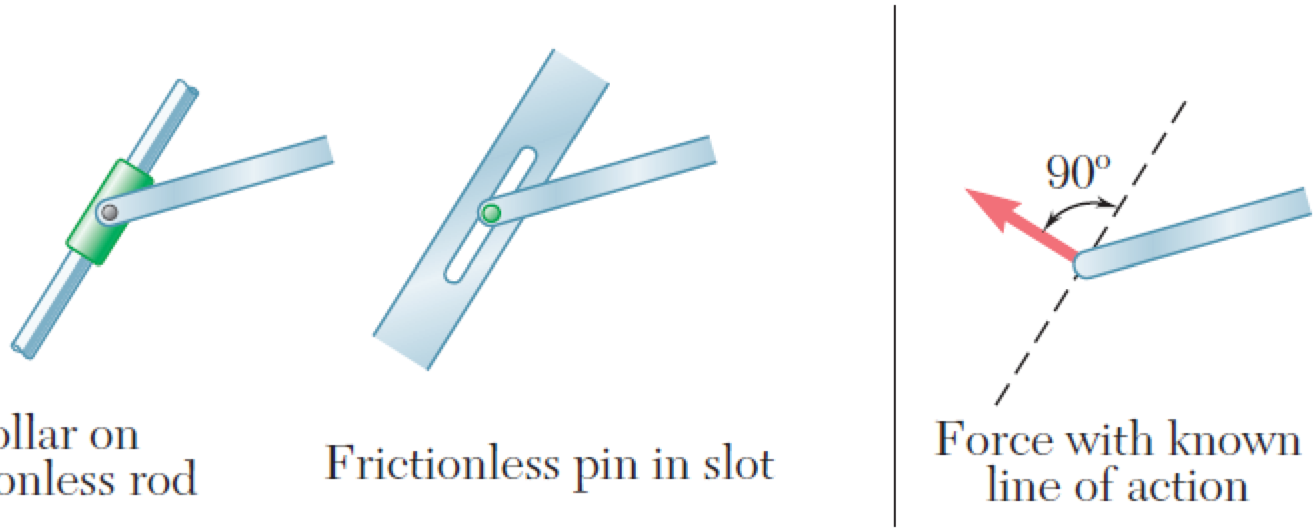


Sign convention of pin (bracket) support: positive along *i,j,k*

Collar-rod and pin-slot supports

2D structure





Collar on frictionless rod

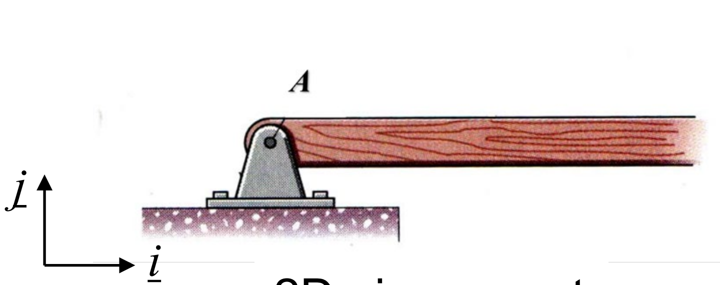
Frictionless pin in slot

Force with known line of action

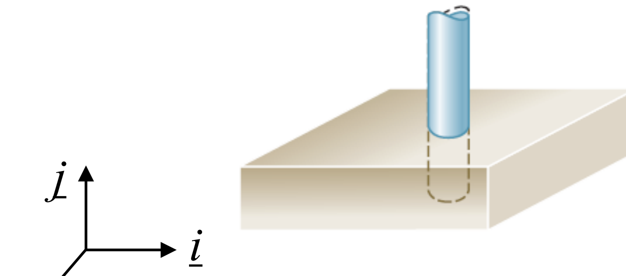
Only one reaction (unknown force) perpendicular to the rod or slot

How to find all constrained forces/couples (named reactions) of a support ?

Tip: find the degree of freedom of the body!



2D pin support

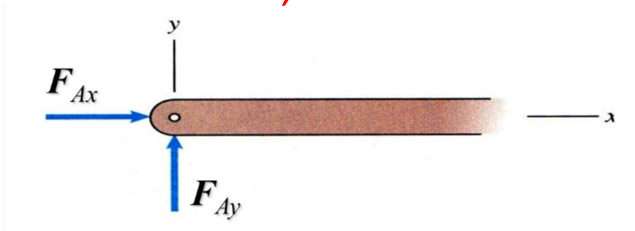


3D Fixed support

2D free body has 3 degrees of freedom

1) Can translate along $\underline{i}$?
2) Can translate along $\underline{j}$?
3) Can rotate in the 2D plane?

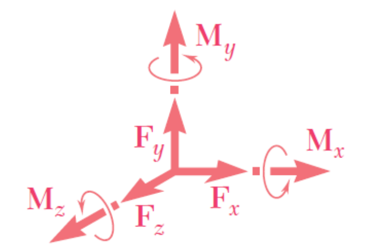
If answer is no, there is a constrained force



F. B. D

3D free body has 6 degrees of freedom

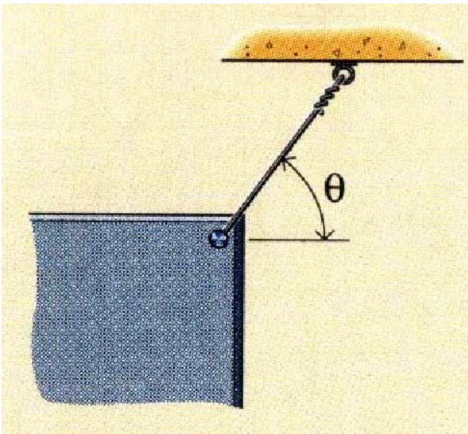
1) Can translate along $\underline{i}$?
2) Can translate along $\underline{j}$?
3) Can translate along $\underline{k}$?
4) Can rotate about $\underline{i}$?
5) Can rotate about $\underline{j}$?
6) Can rotate about $\underline{k}$?

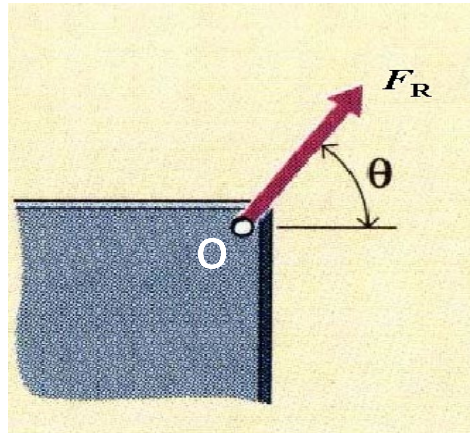


Three force components and three couples

F. B. D

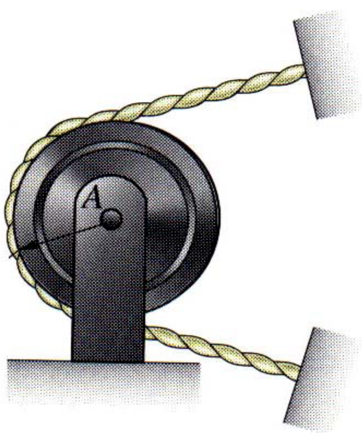
Constraint of rope, cable, chain, link…



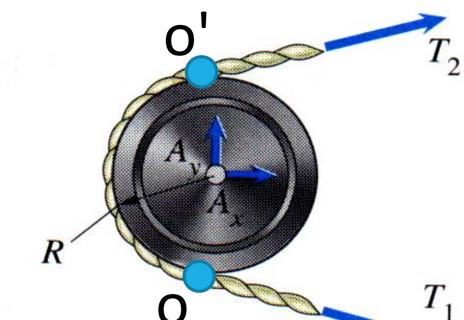


The point of action is the connection point between the studied object and the rope/cable/chain.

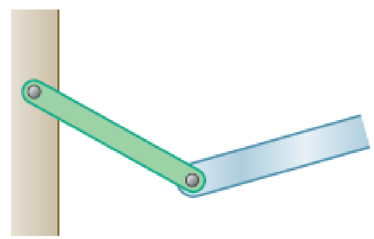
Direction is always along the rope/cable/chain away the point of action.



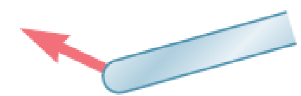
(a)



(b)

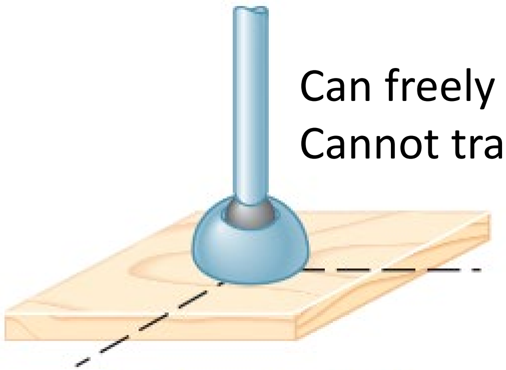


Short link



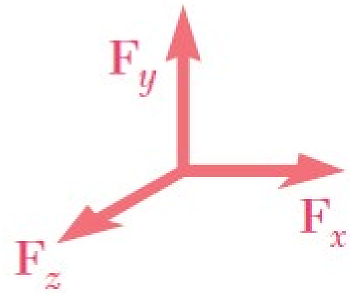
Force with known line of action

Three dimensional (3D) constrains



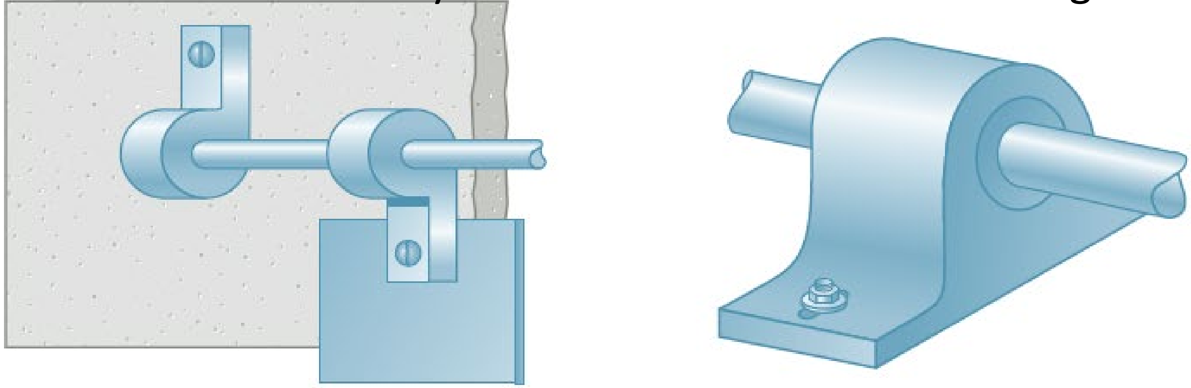
Can freely rotate about x, y, z
Cannot translate along x, y, z

Ball and socket

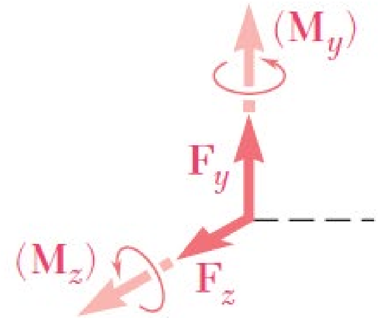


Three force components

Can freely rotate about and translate along axial x



Hinge and bearing supporting radial load only



Two force components
(and two couples; see page 191)

*Review of F. B. D

Free-body diagram (very important !!!)

A **free-body diagram** is a sketch of an object or a connected group of objects, modeled as a single particle/rigid body that is completely isolated from its environment or surrounding bodies and represents the interactions of its environment by appropriate external forces.

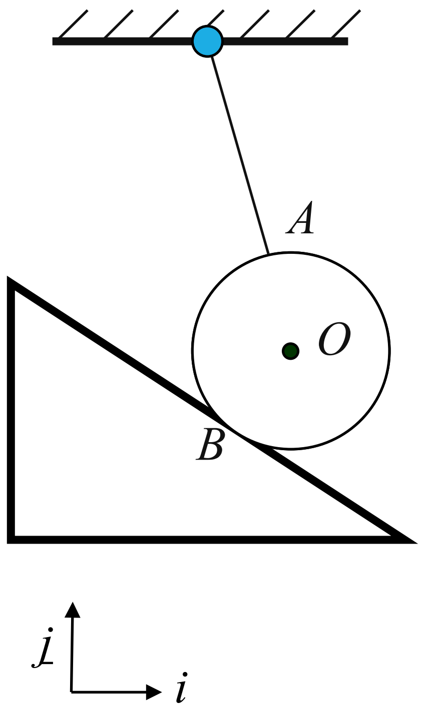
Drawing a free-body diagram is an art, and can be learned **only by practice**. If a correct free-body diagram is constructed, then the balance of the forces can be carried out in a very systematic manner.

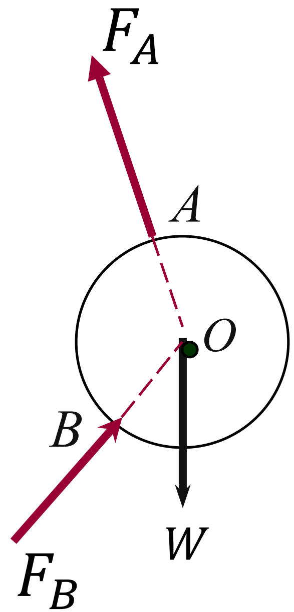
Steps of drawing F. B. D:

1) Isolate the body of interest (to be free body).
2) Draw your axis system (2D or 3D? Cartesian, polar…).
3) Draw all non-constrained applied forces first, such as weight, friction, wind forces.
4) Identify all supports/connections, then draw reactions for each one based on the **F.B.D. Tables**.
5) Draw appropriate dimensions (angles and distances).
6) Remove the internal forces of two free bodies if have.

Example 1

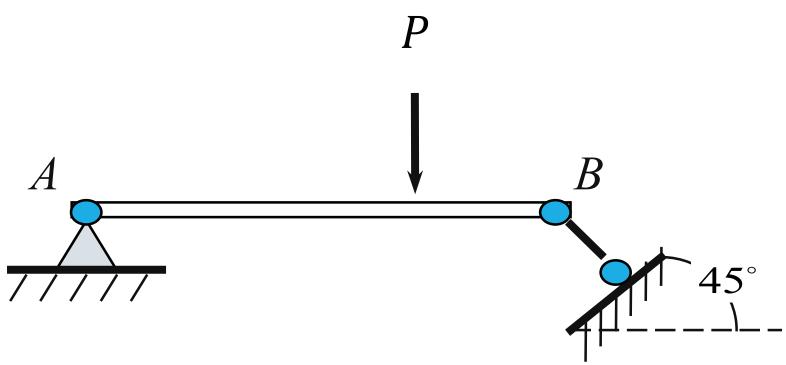
FBD for the ball:

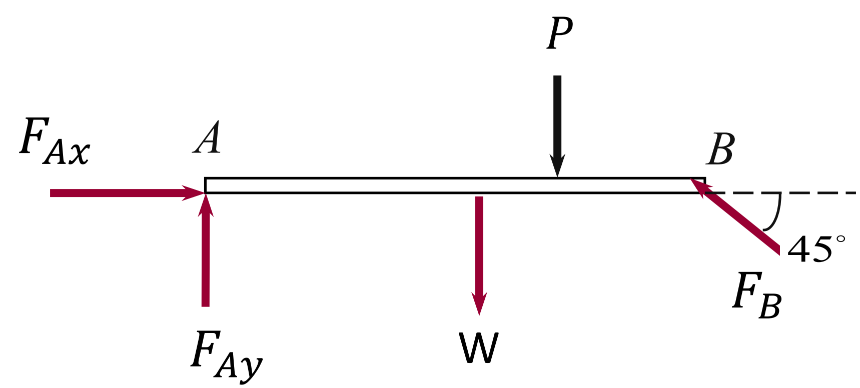




Example 2

FBD for the rod:



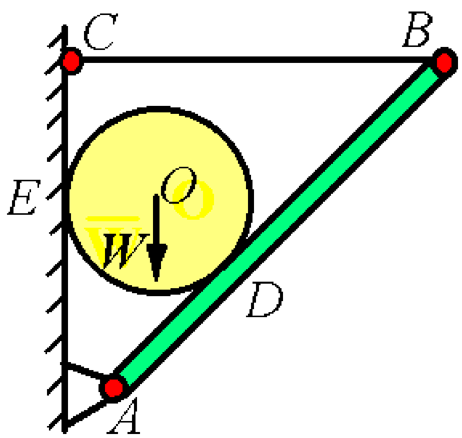


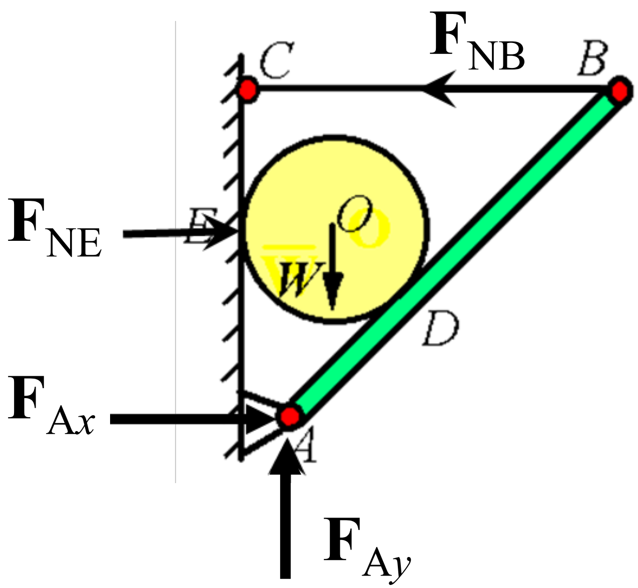
Pin support

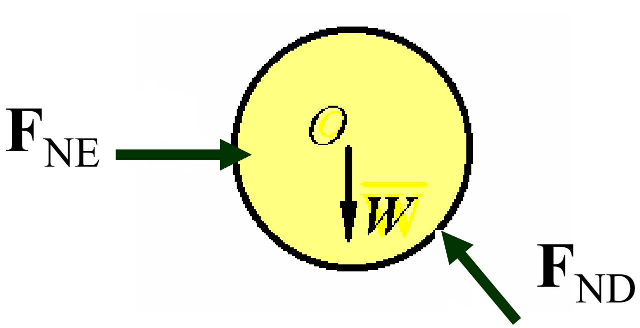
Roller support
on frictionless surface

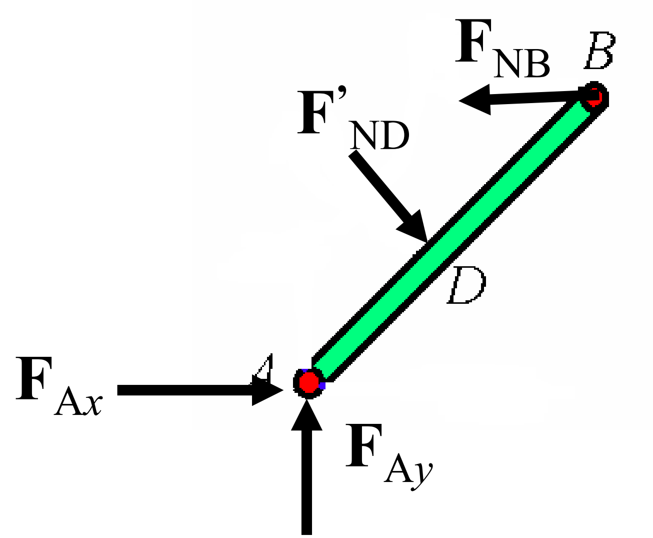
Example 3

FBD for the ball, slim rod (massless), and whole structure:



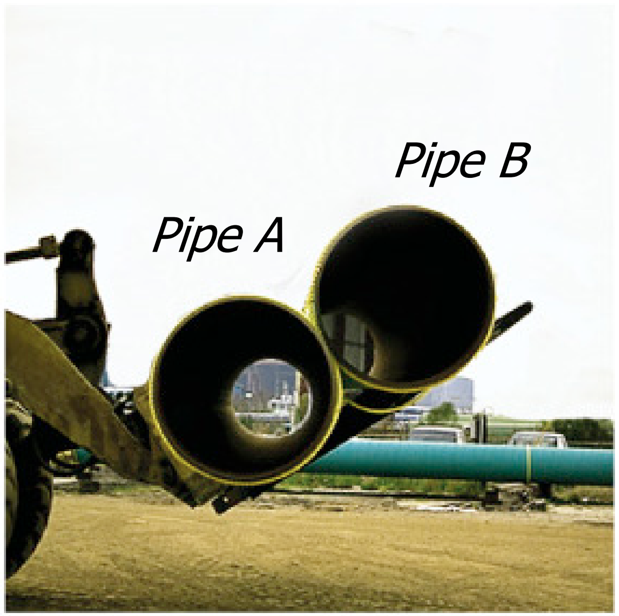




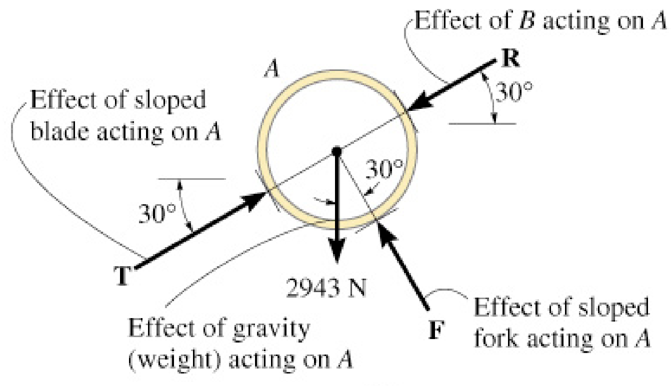


Example 4

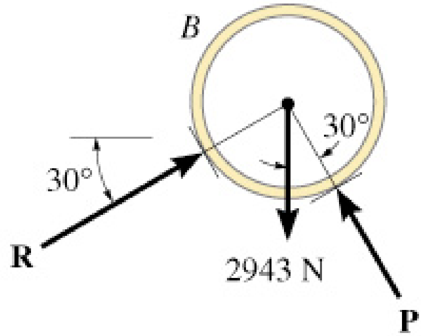
Two smooth pipes, each weighing *W*, are supported by the forks of a tractor as shown in the figure. Draw free body diagrams for each pipe and for both pipes.



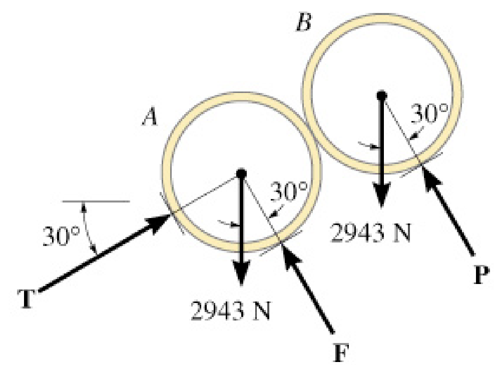
The weight of a body is an external force and its effect is shown as a single resultant force acting vertically down through the body's centre of gravity.



FBD of pipe A



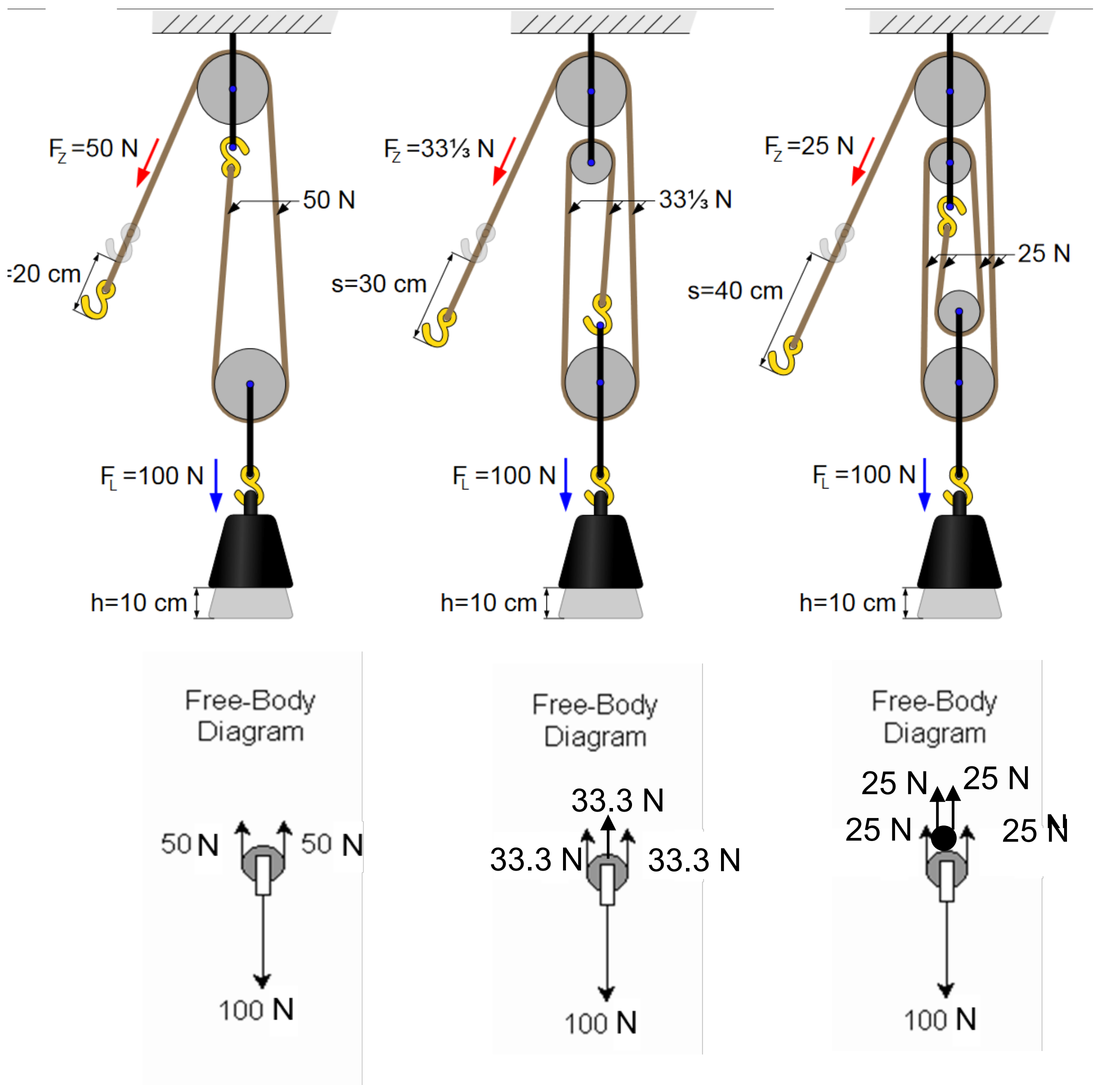
FBD of pipe B



FBD of both pipes

Example 5

FBD for movable pulleys:



Tips:

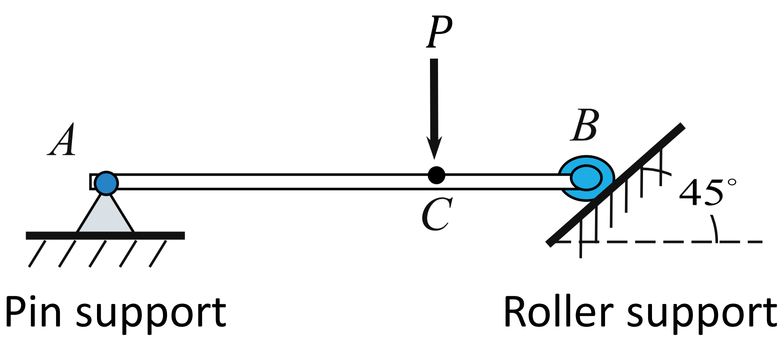
1. Isolate movable pulleys as one rigid body.
2. Each cable carries equal load.

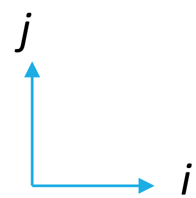
Summary

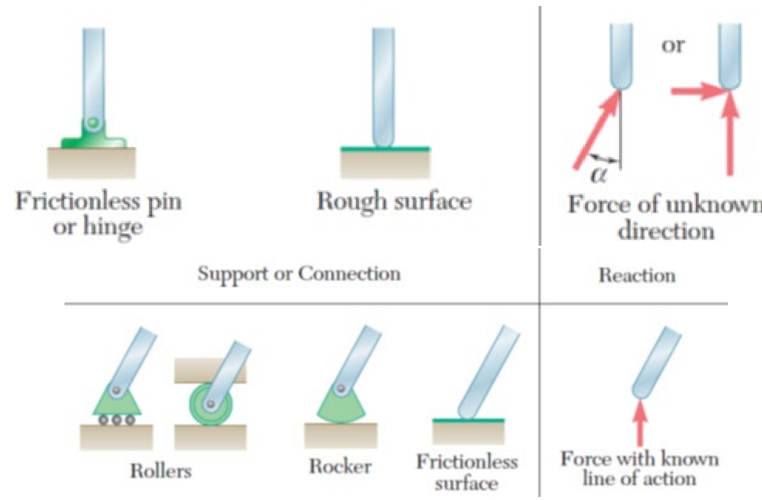
- Drawing F.B.D is the **first** step for solving almost all mechanical problems.
- Drawing a free-body diagram is an art, and can be learned **only by practice**.
- Do the F.B.D test on Quiz/LumiNUS for self-evaluation. To improve your learning of this important concept in this module, personalized practice problems will be provided to you later based on your test results.

Practice problem 1

A rod *AB* has mass *m*. It is the pin support at the end *A.* An external force P is applied on point *C*. Draw the F.B.D of the rod (a) if the roller support of B is on a frictionless surface or (b) on a rough surface.







Steps of drawing F. B. D:

1) Isolate the body of interest (to be free body).
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3) Draw all non-constrained applied forces first, such as weight, friction, wind forces.
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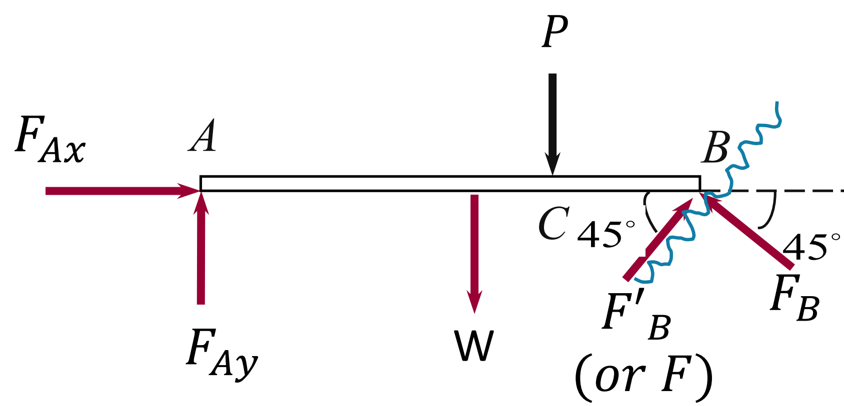
6) Remove the internal forces of two free bodies if have.



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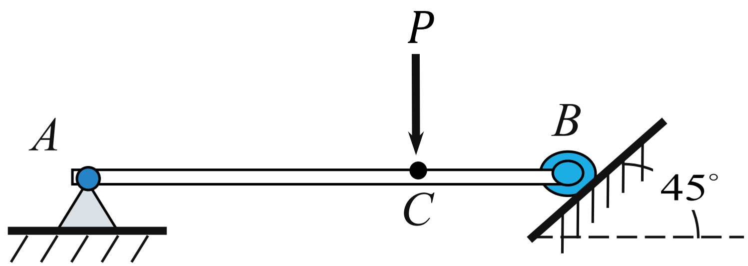
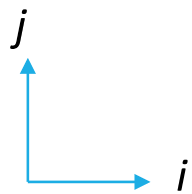
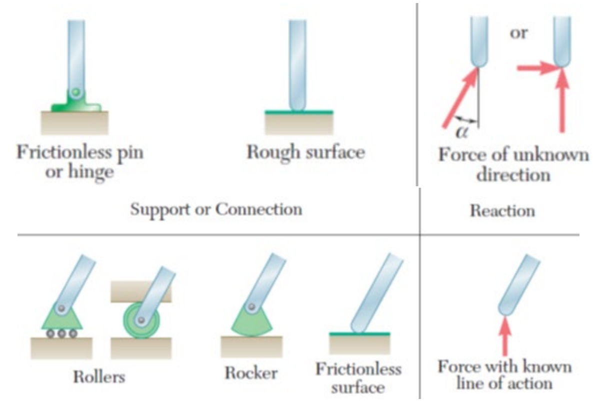
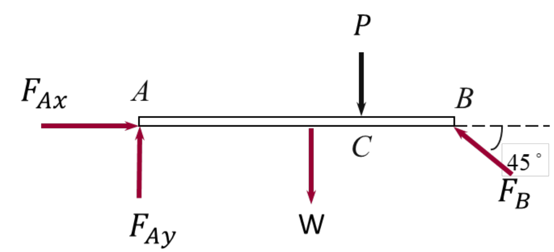


Pin support Roller support

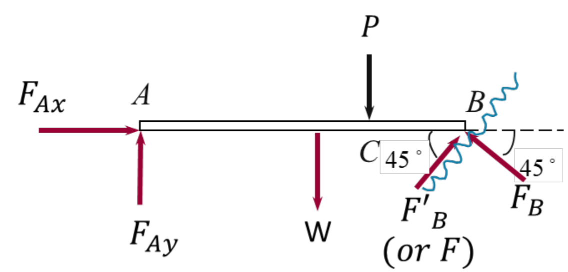




(a)



(b)



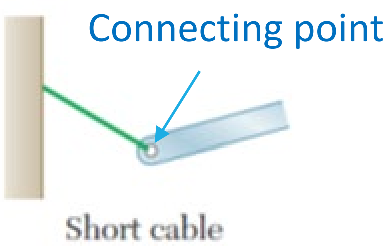
Steps of drawing F. B. D:

1) Isolate the body of interest (to be free body).
2) Draw your axis system (2D or 3D? Cartesian, polar…).
3) Draw all non-constrained applied forces first, such as weight, friction, wind forces.
4) Identify all supports/connections, then draw reactions for each one based on the F.B.D. Tables.
5) Draw appropriate dimensions (angles and distances).
6) Remove the internal forces of two free bodies if have.

Practice problem 2

To demonstrate the importance of the step - Isolate the body of interest (to be a free body) from its supports

Recall the reaction of a soft non-stretchable rope/string/cable/chain… connection.



1. **Point of action of the reaction (tension):** connecting point
2. **Line of action of tension:** the line of cable.
3. **Sense of tension:** away the point of action

Practice problem 3

Draw the tension force on the frame. *C* is a pin and *D* is a pulley. Mass of the frame and cable is negligible.

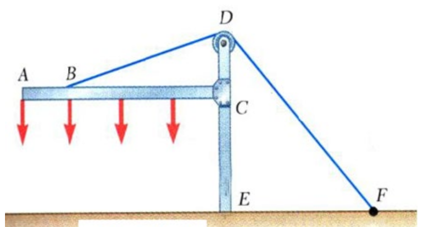
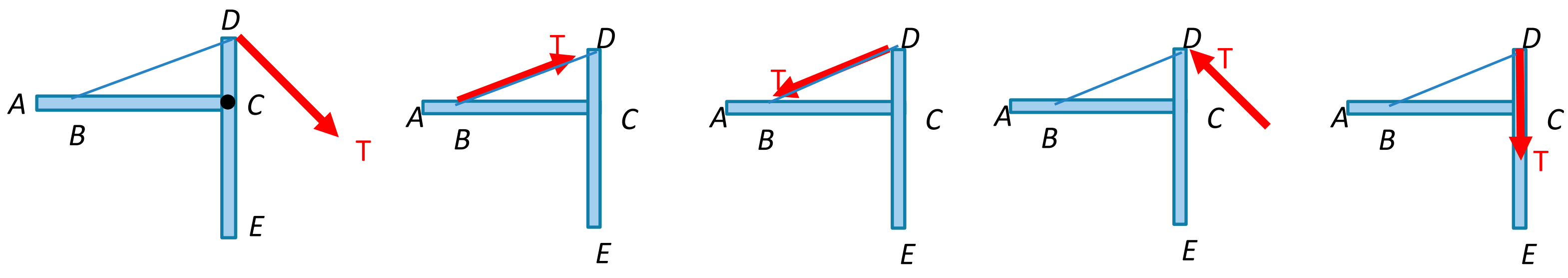


Fig. 3(a)



(a) (b) (c) (d) (e)

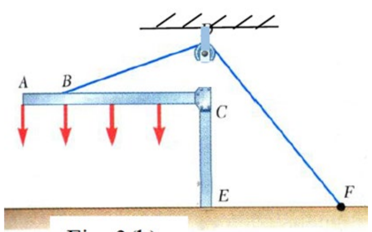
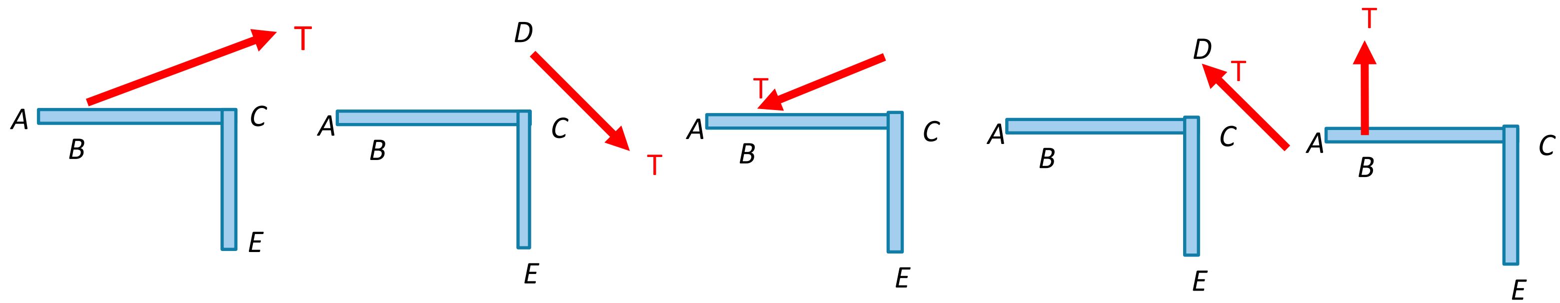


Fig. 3(b)



(a) (b) (c) (d) (e)