Schema: Free-Body-Diagram

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The free-body-diagrams in this article are drawn by using the Statics-Power software from Actus Potentia.

Schema (Wikipedia)

(a) Describes an organized pattern of thought
(b) A system of organizing and perceiving new information
(c) People are more likely to notice things that fit into their schema, while re-interpreting contradictions to the schema as exceptions or distorting them to fit.

Meaning (a)

An important part of success in learning, and consequently, best grades is to develop the habit of organizing what your teachers teach you in class. Experts have well-linked (see the arrows in Figs.-1, 2 below) organized knowledge, novices do not. If you need too much time to finish your homework or you often ask the question, "I do not know where to start solving this problem." your knowledge base is not organized. You must have a "schema!"

Meaning (b)

A schema is like the catalog system at the library, how items are arranged at the grocery store, or how you store your files and folders in your computer. When you acquire new knowledge, you carefully decide where to put it, at the right place in an existing schema or in a new schema. Good schema improves your learning, brings success, and gives you motivation. Learning is fun when you do it the rights way; start now!

Meaning (c)

You first learn schema from your teacher, but eventually you become brave and build your own schema, because you own your schema. You must revisit your schema often to make changes so that new information fits into it and experience improves your schema making ability and removes all contradictions.

Free-Body-Diagram (FBD)

The single most important problem solving tool that physicists and almost all engineers use is FBD. The primary deficiency that engineering undergraduates have is an insufficient aptitude in drawing this "vague and elusive" thing called FBD. The reason behind such inaptitude is that the students do not even consider making a schema for drawing FBD. So I made one for you!

What is the purpose of this write-up?

All text books describe, in great detail, how to draw FBDs. I have taught thousands of students how to draw FBDs. Where is the confusion? From my twenty-five years of experience, the confusion comes in the following:

- Students forget to flip/invert/reverse the direction of the forces to enforce Newton's 3^{rd} Law
- Students get confused when a pin connects several members and also supports a load
- Students get confused when several members are joined at a pin
- Students get confused when several members meet at a pin/roller/clamp support
- Students get confused with frictionless pulleys.

I will show you a few examples to demonstrate the use of the FBD-schema. The examples are chosen to clear up the specific students' confusions listed above.

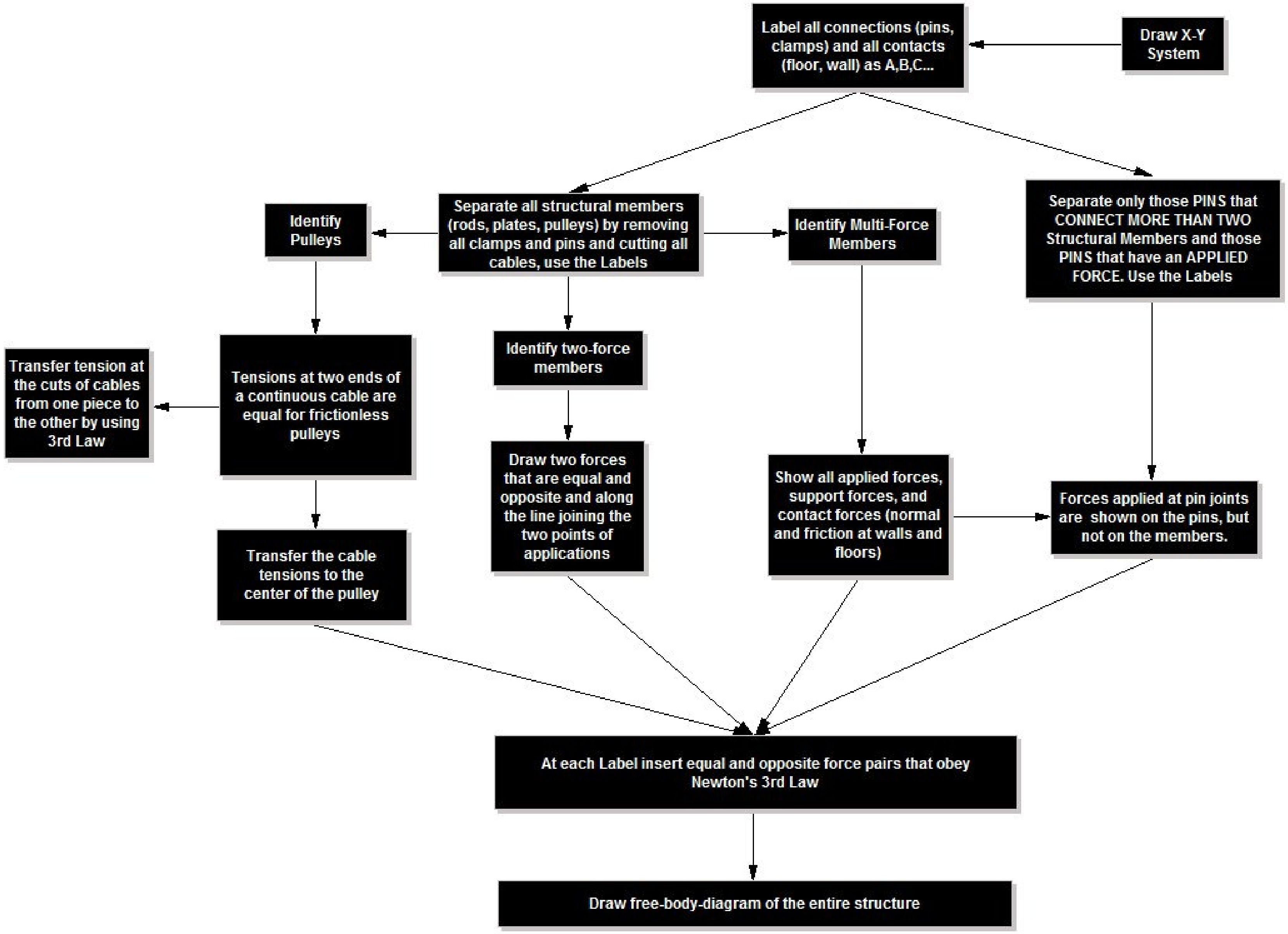


Figure-1: Schema for drawing free-body diagrams.

Two-Force Members

Two-force member is a structural members with only two forces (no couple) acting on it. The shape of the member has no influence on whether a member is two-force. Circular, arced, and crooked, all members can be two-force, as long as two forces are acting on a member. When the weight of the member is included in the analysis and calculation, the weight must be considered as one force. Examples of two-force members are shown in the figure below.

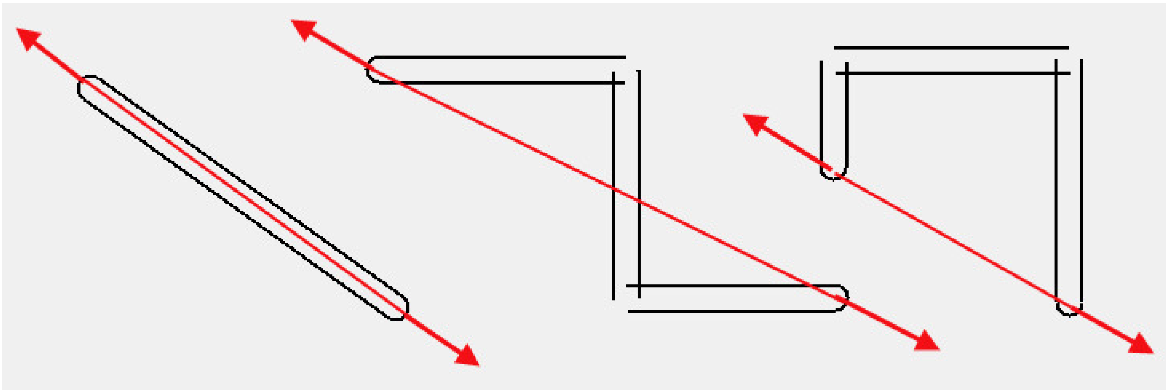


Figure-2: Examples of two-force members.

When a two-force member is in equilibrium, the forces satisfy the following conditions:

- The two forces must act along the line joining the two points of application of the forces
- The forces are equal and opposite.

These two conditions are schematically proved in the diagram, below

I have my personal convention that I always show force on 2-force members as tension

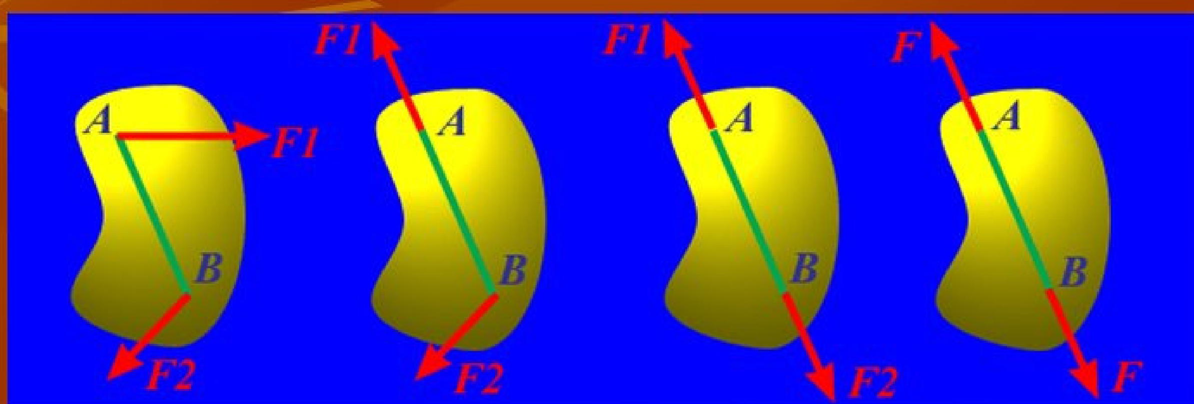
.

Equilibrium of Two-Force Members

Consider the diagrams below from left to right, where two forces are acting on a body.

1. Force *F1* and *F2* are acting at points *A* and *B*, respectively.
2. We balance moment at *B*. Moment due to *F2* is zero. For moment due to *F1* to be zero, it must act along line *AB*.
3. We balance moment at *A*. Moment due to *F1* is zero. For moment due to *F2* to be zero, it must act along line *AB*.
4. For two forces acting along line *AB*, we must have $F1 = F2 = F$

When two forces act on a body in equilibrium, those two forces must have the same line of action, same magnitude, and opposite sense.



Contents

Friction-less Pulleys

A continuous cable wrapped around a friction-less pulley has a constant tension along its length and at the two ends of the pulley. This principle is a consequence of moment balance at the center of the pulley and is schematically shown in the figure below.

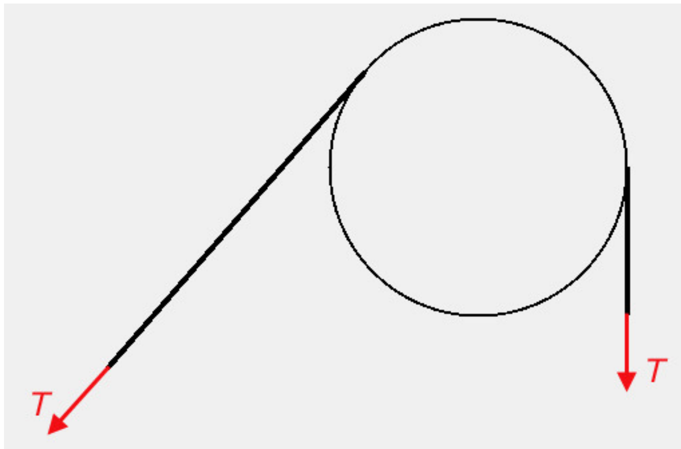
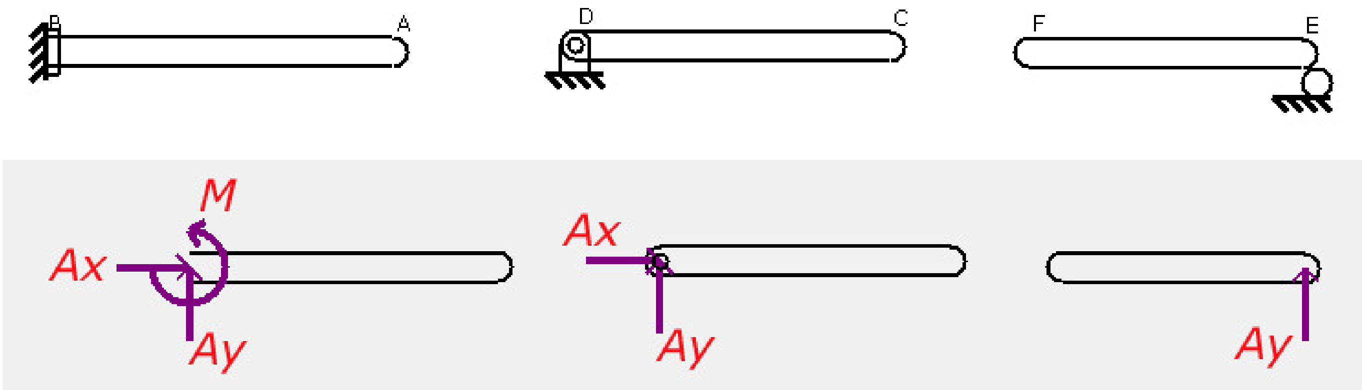


Figure-3: Equilibrium of a friction-less pulley.

Support Reactions

There are three different kinds of supports that provide three different combinations of support forces and moment.

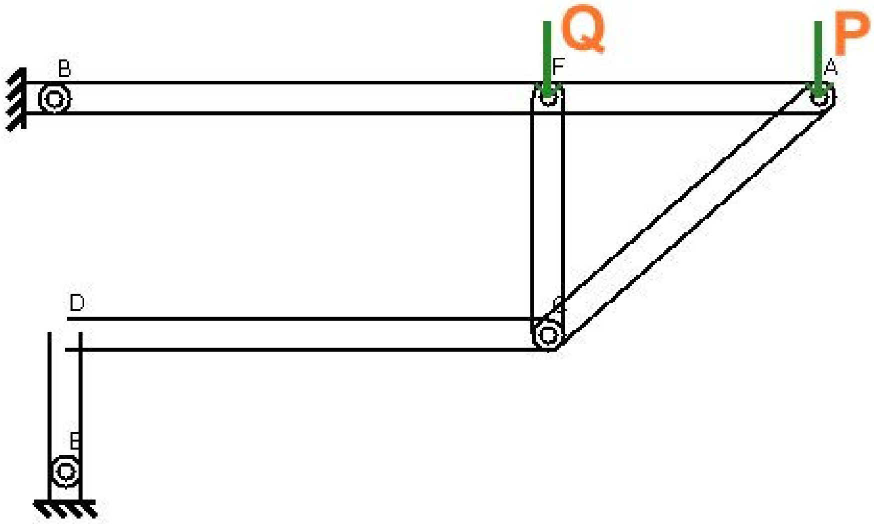
- Clamp support – provides two perpendicular (in two dimensions) forces and one moment
- Pin support – provides two perpendicular (in two dimensions) forces
- Contact/Roller support – provides one force perpendicular to the tangent to the contact. For rough contact, add a friction force along the tangent to the contact.



Free-Body-Diagram Examples

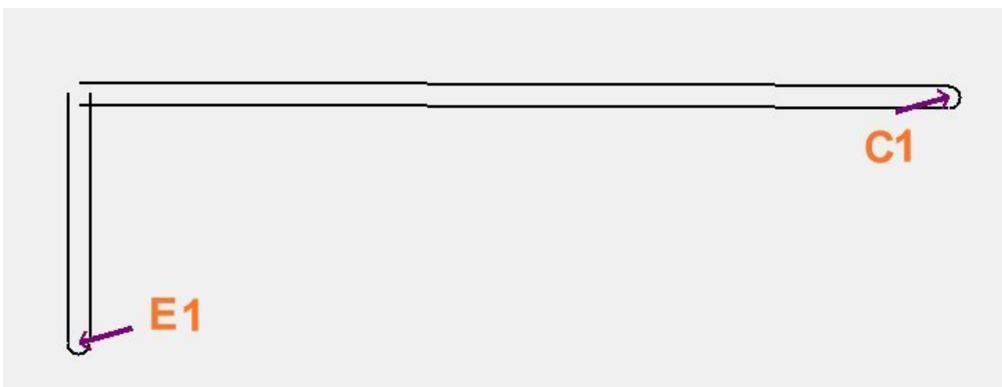
We will now draw fee-body-diagrams for three frames by following the schema of Figure-1.

Example-1

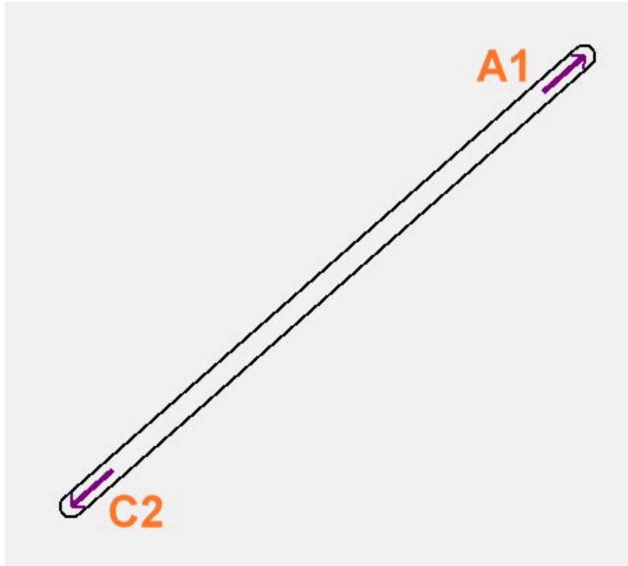


- Two force members: CDE (L-shaped 2-force members), FC, and AC
- Multi-force member: AFB
- Pins with load are F and A; pin C connects more than two members (draw separate FBDs for these pins)

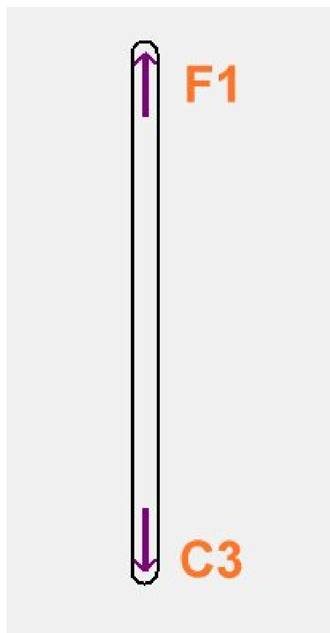
FBD of 2-force members



Member CDE: C1 = E1. Note that the force at pin support at E is simply E1 and need not be broken up into x and y components.

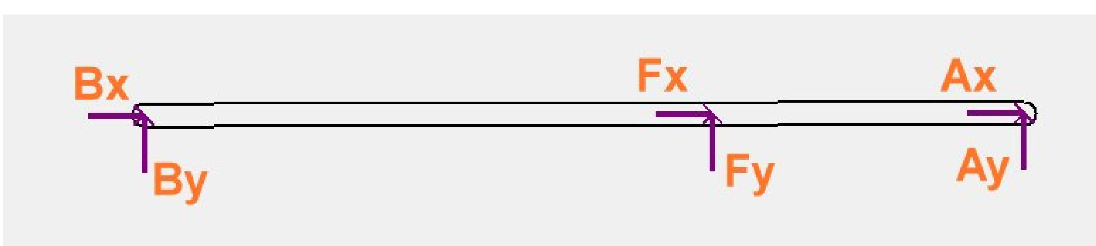


Member AC: C2 = A1



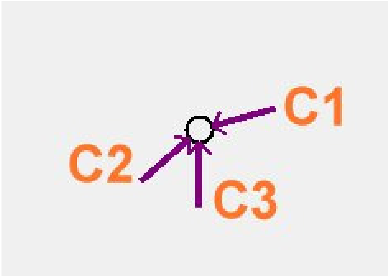
Member CF: C3 = F1

<u>FBD of multi-force member</u>

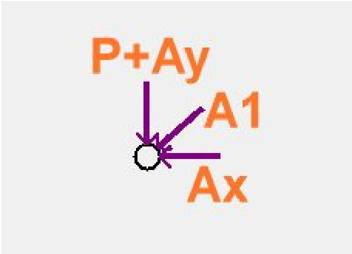


Member BFA

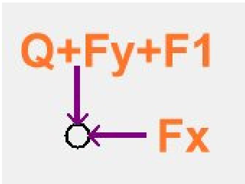
FBD of pins with force and pins that connect more than two members



FBD of Pin-C: The directions of C1, C2, and C3 are switched due to Newton's 3rd Law.

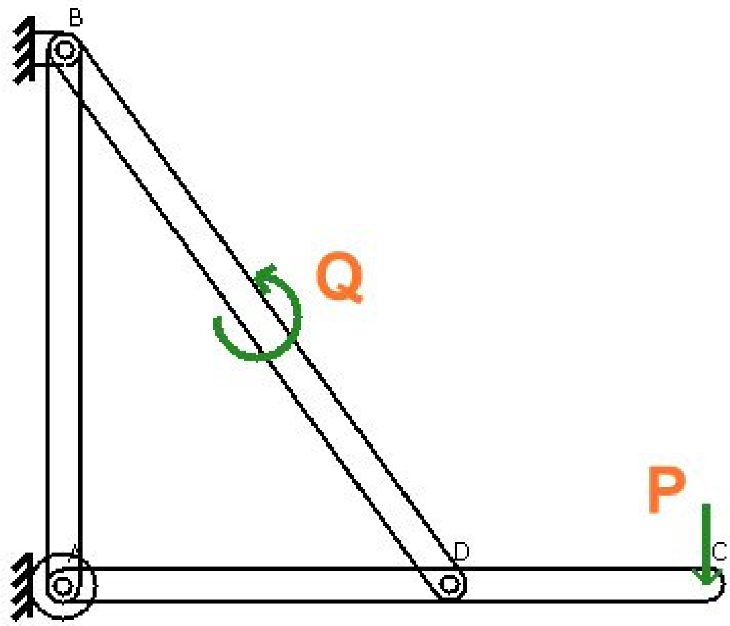


FBD of Pin-A: The directions of Ax, Ay, and A1 are switched due to Newton's 3rd Law.



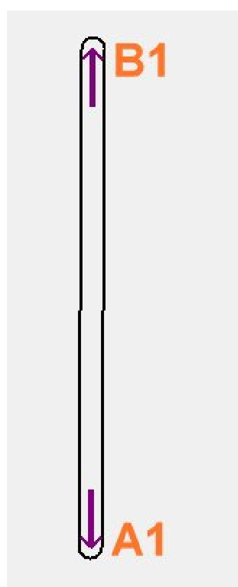
FBD of Pin-F: The directions of Fx, Fy, and F1 are switched due to Newton's 3rd Law.

Example-2



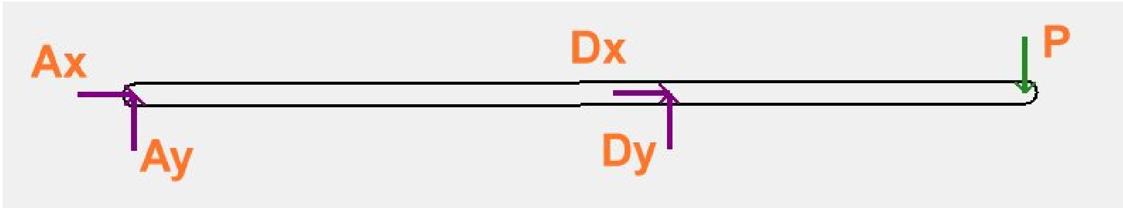
- Two force member: AB
- Multi-force members: BD, ADC
- Pins A and B connect more than two members (draw separate FBDs for these pins)

FBD of 2-force member

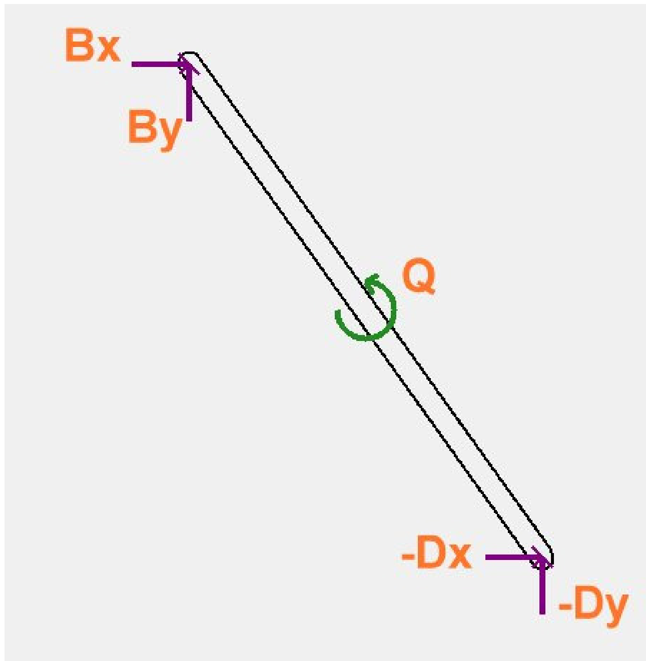


Member AB: A1=B1

FBD of Multi-force Members

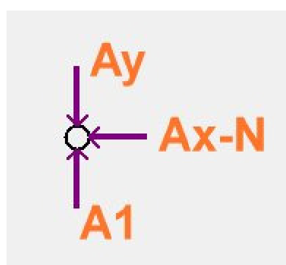


Member ADC

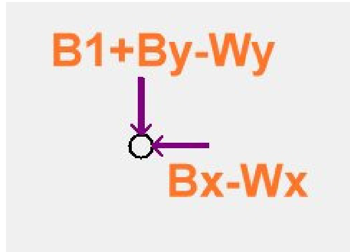


Member BD. Note how Dx and Dy are switched to –Dx and –Dy
due to Newton's 3rd Law.

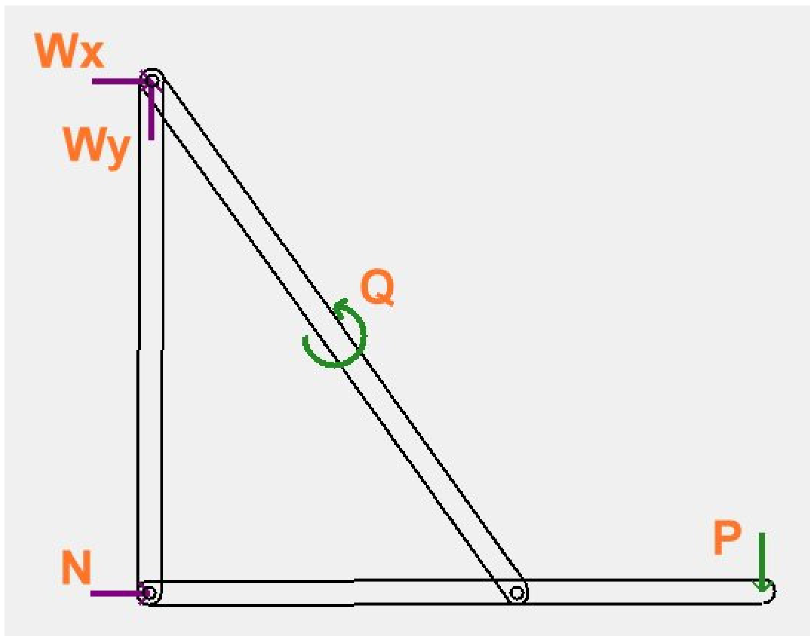
<u>FBD of pins that connect more than two members</u>



FBD of Pin-A: The directions of Ax and Ay are switched due to Newton's 3rd Law.
N is the contact force from the roller support. N to the right is the same as (-) N to the left.
Note that N is shown to the right in the FBD of the whole structure, below.

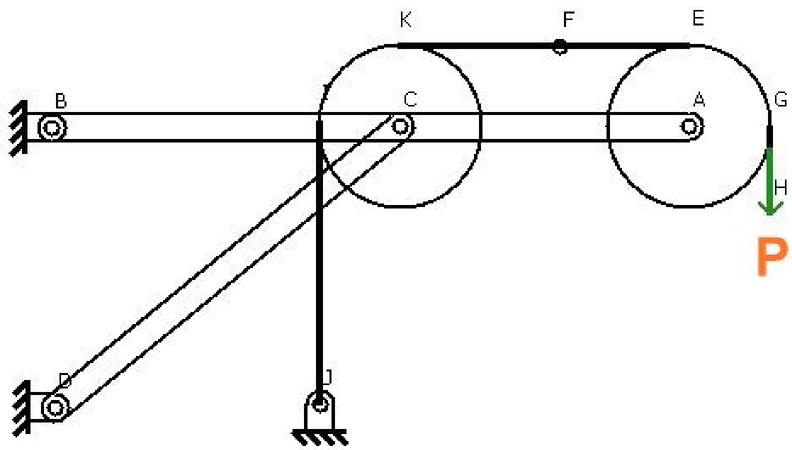


FBD of Pin-B: The directions of Bx, By, and B1 are switched due to Newton's 3rd Law.
Wx and Wy are the force from the pin support.
Wx to the right is the same as (-)Wx to the left.
Wy upward is the same as (-)Wy downward.
Note that Wx is shown to the right and Wy is shown upward in the FBD of the whole structure, below.



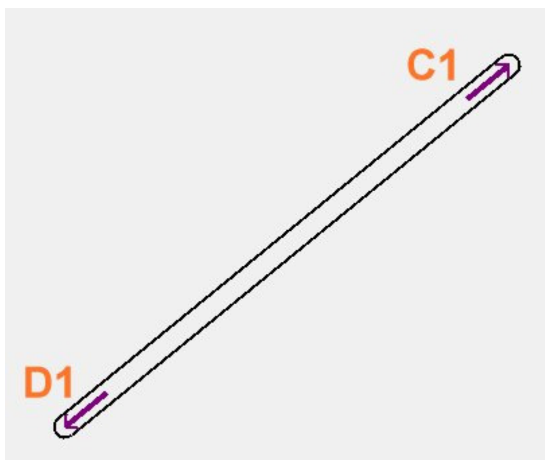
FBD of the whole structure.
Note that when we put the pieces back together,
the equal and opposite (Newtons' 3rd Law, action equals opposite reaction)
forces disappear. Only the support forces, from the pin and the roller, remain.

Example-3



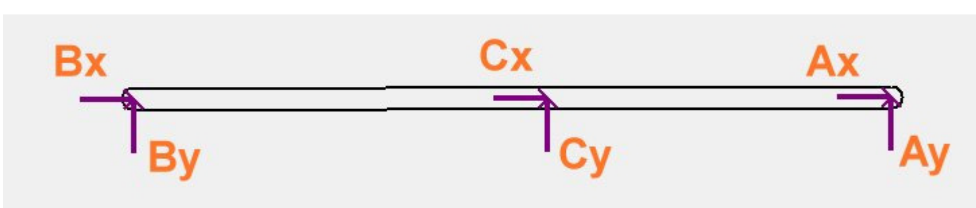
- Two force member: CD
- Multi-force members: BCA
- Pin C connects more than two members (draw separate FBD for this pin)

FBD of two-force member



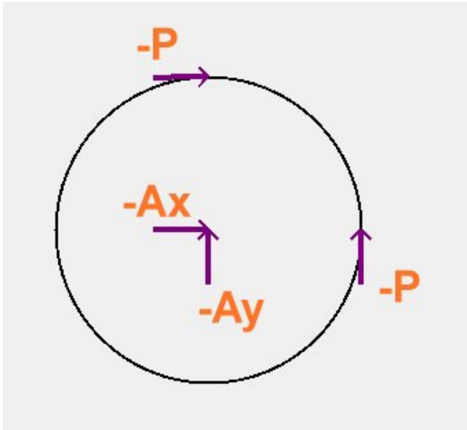
Member CD: C1 = D1

FBD of multi-force member

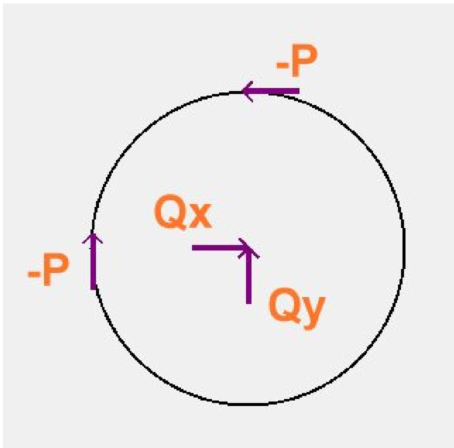


Member BCA

FBD of the pulleys

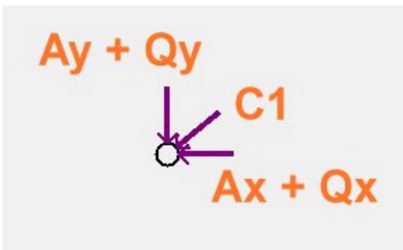


Pulley on the right: (-)Ax to the right is the same as Ax to the left.
(-)Ay to the right is the same as Ay to the left.
Directions of Ax and Ay are switched due to Newton's 3rd Law.
(-)P up is the same as P down, the load on the cable.
Note that the moment is balanced at the center of the pulley.



Pulley on the left: Note that the moment is balanced at the center of the pulley.

FBD of pins that connect more than two members



FBD of Pin C: Directions of Ax, Ay, Qx, Qy, and C1 are switched due to Newton's 3rd Law.