System Schema & Free Body Diagrams

PHYSICS 203, PROFS. MAX BEAN & DANIEL YAVERBAUM
JOHN JAY COLLEGE OF CRIMINAL JUSTICE, THE CUNY

I. Conceptual Framework: Newton's Laws

From this point forward, let the following choice of English words (and mathematical symbols) capture our working versions of Newton's Three Laws of Motion:

i. Unless acted on by a net external force, an object at rest will remain at rest and an object in motion will remain in motion at the same speed and in the same direction.

ii. $\sum \vec{F} = m\vec{a}$
(where $\sum \vec{F}$ means the ***sum of all external forces*** which, once negative signs are acknowledged, means the same thing as ***net external force***. Note that F and a are both vectors, while m is a scalar.)

iii. If x exerts a force on y, then y exerts a force on x of equal magnitude and opposite direction.

Please answer each of the following with three to five complete sentences of your own words.

You must include at least one original and **SPECIFIC** example in each of your responses.

In Newton's 1st and 2nd Laws of Motion, what precisely is meant by a "***net*** external force"? In order to clearly and distinctly define a net external force, your response **MUST** include all of the following:

a. a specific example of a net external force acting on an object,
b. a specific example of a net ***non***-external force acting on an object and
c. a specific example of an external ***non***-net force acting on an object.

Please label each of these examples with the corresponding letter.

II. System Schemata

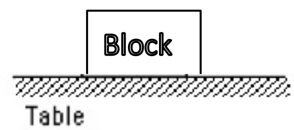
A ***system schema*** (plural: system schemata) is a special type of diagram that is designed to help you identify all the forces acting on a ***particular object***, called the "***Object of Interest***."

Ultimately, in advanced physics, this question of what forces are acting on an object can get very difficult, but for the purposes of this course, there is a very simple answer:

If two objects are TOUCHING, they exert a force on each other. And the ENTIRE EARTH exerts a gravity force on every object that is near its surface (whether it is touching it or not).

Therefore, to draw a system schema, you simply need to identify all the objects that are touching the object of interest. Each of these objects will be represented by a CIRCLE in your system schema. So will the entire earth (unless these objects are not on earth), and of course the object of interest itself.

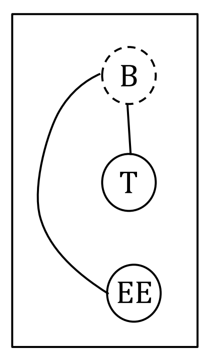
For example: consider the simple scenario to the right, in which a block is sitting motionless on a tabletop.



There are two objects shown in the diagram, but we generally assume that scenarios of this kind are occurring *on earth*, so there are actually three objects interacting in this scenario: the block, the table, and the entire earth. In this case, our object of interest will be the block.

To create a system schema,

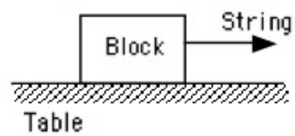
1. Give the three objects convenient nicknames, for example: B, T, and EE.
2. Draw a dotted circle to represent the object of interest and label it.
3. Draw a solid circle to represent the other objects in the scenario and label them.
4. Draw a ***line*** connecting the object of interest to all the other circles. These lines represent ***force-interactions*** between the object of interest and the other objects that are interacting with it.



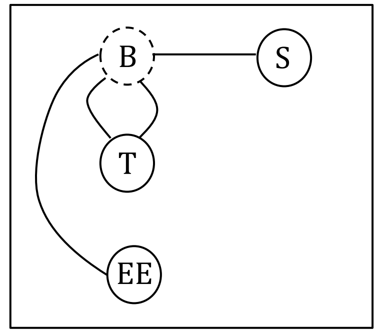
When you have completed this step, the system schema for the simple block & table scenario should look something like the diagram to the right. We have arranged this diagram with the block on top and the entire earth at the bottom, because that's an easy, intuitive way to draw it—but, the location of the circles in a system schema does not really matter—and neither does the length of the lines. What is important is simply that each force-interaction be represented.

One important thing to understand about the system schema is that every line represents a force ***interaction*** between ***two*** objects. That means that, according to Newton's Third Law, each line represents ***two*** forces: object *a* pulling/pushing on object *b*, and object *b* pulling/pushing on object *a*.

Here's a more complicated scenario, in which the block is still sitting on the table, but now there is a string pulling the block to the right. There are now three objects, plus the entire earth.



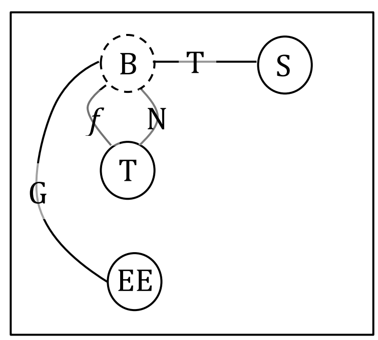
Here is a system schema to represent this new scenario. Notice that there are ***two*** lines between the block and table. This is because those objects have ***two types of interaction***—in other words, they have two pairs of forces between them. First of all, the block is pushing ***down*** on the table, and the table is pushing back ***up*** on the block. This is a pair of forces that runs ***perpendicular to the surfaces of the objects***. But, if the block is moving, and the table is not perfectly smooth, then the table will also be pulling the block ***to the left***, resisting the block's motion (and by Newton's Third Law, the block will be pulling the table ***to the right***.) This is a pair of forces ***parallel to the surfaces of the objects***.



Once you have completed your System Schema, you ***may*** also find it ***helpful*** to label each line in it with the type of force-interaction that it represents. In this course, there are only four basic types of force-interactions:

1. Objects may push each other in a direction perpendicular to their surfaces (like the block pushing the table down & the table pushing the block up); these are called "normal" forces. (We'll talk about why later.)
2. Objects may push each other in a direction parallel to their surfaces (like the table pushing the block to the left); these are called "frictional" forces.
3. Objects may pull each other by means of some long, rope-like thing (e.g. a string or an arm or a chain); these are called "tension" forces. Note that a tension force always acts exactly parallel to (in line with) the long, rope-like thing that's doing the pulling.
4. Objects may pull each other towards each other without touching by means of an invisible, magical power; these are called "gravitational" forces.

If you label all the lines in your system schema, it should look something like the diagram to the right. Labeling the force lines is OPTIONAL.



One VERY IMPORTANT thing to note: A System Schema typically shows the interactions between objects at a single POINT in time. It does not show a ***process*** or a ***period*** of time. It shows a single INSTANT. Sometimes, a situation will be fairly stable, and the interactions will remain the same for a period of time: for example, maybe the string pulls the block for several seconds. In that case, the SS may refer to the whole period of time.

For further reading on system schemas, see the this article
http://modeling.asu.edu/modeling/SystemSchemas_LTurner_4-03.pdf

III. Free-Body Diagrams (FBDs)

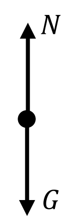
A system schema shows you ***how many*** forces are on an object and what objects they're coming from, but it does not show anything about the ***direction*** or ***magnitude*** of those forces. To represent direction & magnitude, we use another type of diagram, called a **Free-Body Diagram** (FBD). A free-body diagram is a special type of ***vector*** diagram. In this case, the vectors being depicted are forces. All forces are vectors.

An FBD only shows the object of interest and the forces that are acting ***ON*** that object at a given ***instant*** in time. It does ***not*** show the other objects, and it does ***not*** show the forces exerted ***BY*** the object of interest.

Always draw a system schema ***first***, ***then*** an FBD. The system schema is a tool to help you make the FBD. To make an FBD from a system schema:

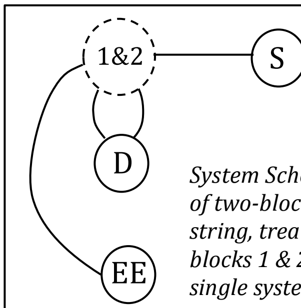
1. Draw ***a dot*** to represent your object of interest (O. of I.).
2. Look at your system schema. Count the lines connecting the object of interest to other objects in the system schema. <u>For each line in your SS, there is a force exerted ***ON*** the O. of I.</u> (there is ***also*** a force exerted ***by*** the object of interest, but you don't care about that right now). Ask yourself: which DIRECTION is each of those forces on the O. of I. pointing?
3. For each force on the O. of I., draw an arrow. Label each arrow with the ***type of force*** that it represents. Do not label it with the name of the object that is exerting it. Label it with the type of force: Normal (N), Tension (T), Friction(*f*), or Gravity (G). (Refer to the list of the four types of forces on the preceding page.)

For example, in the simple block-on-table scenario above, we see two lines touching the block. Therefore there will be two arrows in the FBD (shown to the right →). One will represent the table pushing UP on the block: this is a ***normal*** force. The other will represent the entire earth pulling DOWN on the block: this is a ***gravity*** force.

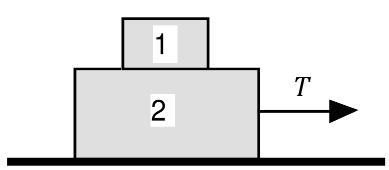


(Note: these two forces do NOT form a Newton's 3rd Law pair.)

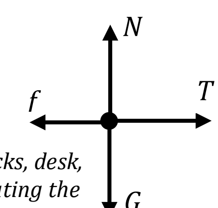
You can also draw a System Schema and an FBD for a ***system*** of objects. The system schema shown to the right represents the two-block, desk, & string scenario shown below:



System Schema of two-block & string, treating blocks 1 & 2 as a single system.



In this example, the two boxes are treated as a single system. When drawing an FBD for this two-block system, you will only include forces acting ***on*** the system—in other words forces that are ***external*** to it. You will not include forces of the two blocks acting on each other, since these are ***internal*** to the system.



FBD of 2 blocks, desk, & string, treating the two blocks as a single system.

IV. COMMON SCENARIOS

On a clean sheet of paper, do ***three*** things for ***each*** of the scenarios on the next page:

i. Draw a SYSTEM SCHEMA.
ii. Draw an FBD of the object indicated in each scenario. Without numbers, take the SIZE and DIRECTION of each arrow seriously
iii. For EACH arrow in the FBD, describe a "Newton's 3rd Law Pair" in ENGLISH. ***For example***, if some arrow represents a rope pulling a horse to the north, you would write "rope pulls northward on horse; horse pulls southward on rope".

SCENARIOS:

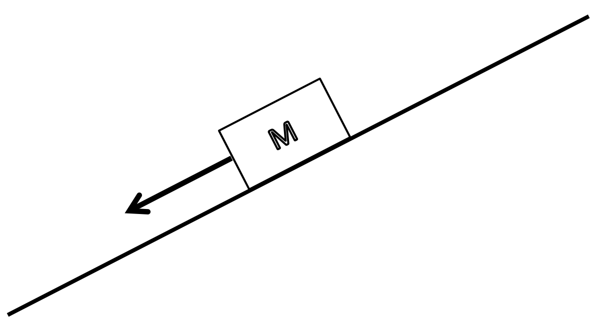
A) A football is moving upwards towards its peak *after* having been kicked by the punter. Draw an FBD of the FOOTBALL. (Ignore "air resistance.")

B) A girl is suspended motionless from a bar which hangs from the ceiling by two ropes. Your FBD should focus on the BAR.

C) A rightward-pushing hand is applied to a book in order to move it across a desk at constant velocity. Your FBD should focus on the BOOK. (DO consider "friction" between the book and the desk, but ignore "air resistance.")

V. INCLINED PLANE ("Galileo Track").

Consider the following scenario (the "Inclined Plane"):



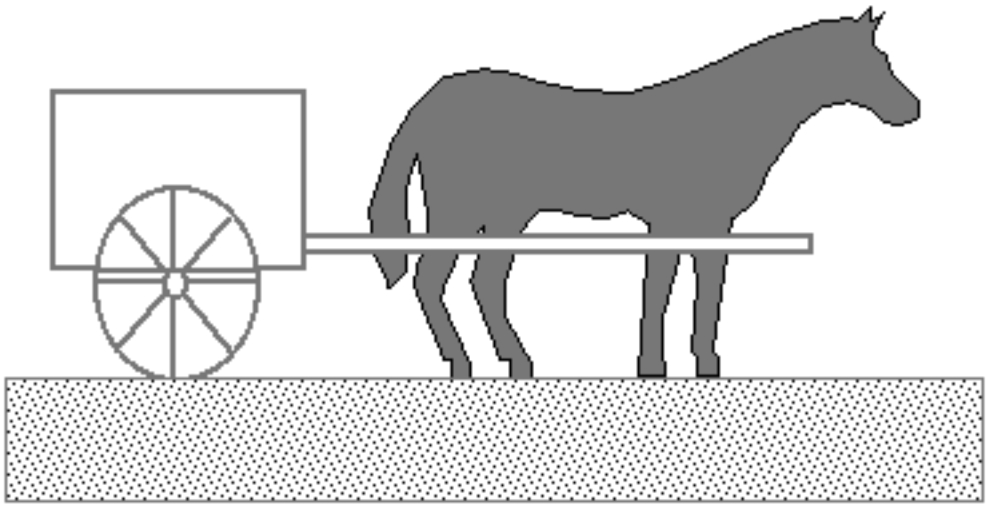
A mass (M) slides down a straight ramp. The ramp is extremely smooth, perhaps due to a cushion of air. Friction effects, therefore, are small enough to be "neglected" (ignored).

A) Draw a SYSTEM SCHEMA for this entire situation.

B) Draw an FBD for the mass.

VI. YE OLDE HORSE & CART

Consider the following scenario (the "Horse & Cart"):



A horse accelerates a cart along rough (frictional) ground.

A) Draw a SYSTEM SCHEMA focusing on the CART.

B) Draw an FBD for the CART.

C) What force propels the CART forwards?

D) Draw a SYSTEM SCHEMA focusing on the HORSE.

E) Draw an FBD for the HORSE.

In one to three complete sentences of your own words, answer the age-old question:

F) How/why does the HORSE move FORWARDS?!