Free Body Diagrams

Representations Series

Instructor's Guide

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Developed by the Teaching and Learning Laboratory at MIT
for the Singapore University of Technology and Design

Introduction

When to Use this Video

- In Phys 101. This video can be viewed in a lecture or recitation/discussion section, or can be assigned for students to watch outside of class. If the class has prior physics experience from other courses, the video should be assigned to be watched before Lecture #9. For a class with no prior experience, it can be assigned before Lecture #10.
- Prior knowledge: Students should have been exposed to free body diagrams in a previous course or earlier in this course. They should have drawn a few, but do not need to be experts in their creation or use.

Key Information

Duration: 14:09
Narrator: Prof. John Belcher
Materials Needed:
• Writing implement
• Paper

Learning Objectives

After watching this video students will:

- Improve their ability to draw free body diagrams.
- Be able to identify errors in diagrams and correct them.
- Recognize free body diagrams as representations of forces, and connect them with real-world objects and phenomena.

Motivation

- Free body diagrams are a key problem-solving strategy for physics and engineering students. They help students visualize physical situations, infer the motion of objects, and keep track of multiple forces more easily.
- Most students have trouble spotting errors in their diagrams and the diagrams of others. This video specifically tackles common difficulties with and misuse of free body diagrams.

Student Experience

It is highly recommended that the video is paused when prompted so that students are able to attempt the activities on their own and then check their solutions against the video.

During this video students will:

- Follow along by creating free body diagrams of their own.
- Find errors in a set of diagrams presented in the video.

Video Highlights

This table outlines a collection of activities and important ideas from the video.

Time	Feature	Comments
1:50	Guidelines for drawing FBD	
2:37	Falling block	Very simple, single force
3:00	Block on table	Builds to more complex example with push, normal force, and tilted surface.
4:06	Bungee jump video	Drawing of diagram starts at 4:29. Good opportunity for discussion of why the forces are what they are at the bottom.
5:32	Dog sled example	
6:23	Golf ball example	Note that the diagram is drawn *immediately after* the ball loses contact with the ground.
7:21	Beginning of diagrams with errors section.	Playing this section from here will include the introduction, which may help keep students from thinking that every diagram they see is correct.
8:04	Softball pitch example	Newton's 1st Law ignored
8:43	Block on surface example	Decomposed forces not removed
9:25	Car example	Velocity on diagram and no normal force.
10:11	Parachuter	Too many forces included
11:30	Car on road	This animation shows how changing forces on a car alter its movement.
12:20	When to avoid using free body diagrams	Set of 3 examples

Video Summary

The video consists of four sections: a brief refresher on the method for drawing free body diagrams, examples of free body diagrams with an opportunity to practice, examples of situations in which diagrams have been drawn incorrectly (and corrections for them), a final segment that draws connections between free body diagrams and the physical situations they describe.

Phys 101 Materials

When appropriate, this guide is accompanied by additional materials to aid in the delivery of some of the following activities and discussions.

Pre-Video Materials

Two activity handouts are included in the appendix for this guide, as well as in a separate PowerPoint® file (Handout.pptx in the Pre-video and Post-video folders). The intent is to have one used before the video and one after. Have students gather in groups of 2-3. Only one person per group will need a copy of the handout. Once the groups have had enough time to draw the diagrams, have a few groups describe their diagrams. Call for opposing viewpoints and alternative diagrams.

1. Here are some suggestions and comments for facilitating discussion of the airplane handout on page A1:

- Some students may neglect the gravitational force and normal force. Rather than insisting on their inclusion, ask whether they are necessary and what benefit we might get from including them.
- Some students may have drawn a diagram of the plane by mistake.
- The horizontal forces are not balanced, which they should be.

There are two multiple-choice questions in the appendix. These questions work well with classroom response systems (clickers), but can also be used with a simple vote-by-hand-raise. When using these items, remember that they are discussion builders, not problems that the students need to answer correctly in order to get credit. Do not use these as test items.

Pre-made PowerPoint® slides are available at the end of this guide, or in the "Clickers Pre.pptx" file.

2. In the motorcycle problem on page A2:

- Choices 1 and 2 are probably the most defensible.
- The motorcycle may be tilted, but its normal force still points directly upward (perpendicular to the line of contact between the tire and road). If students have difficulty with this, ask them to imagine the tire in contact with the road.

3. In the hot-air-balloon problem on page A3:

- This is a "choose all that apply" problem. If your clicker system is not set up for that, you will need to make some alterations.
- Some students may want to list both weight and buoyancy; others may consider the sum of the two to be a sort of "negative weight." Still others will list both weight and the influence of gravity. It will be helpful to state that you are not answering any questions until after the vote is taken.
- Always ask what other force students would like to have if #6 shows up. Typical choices include wind, a force from the heat/flame in the balloon, and tension pulling downward from the basket. The latter two will need discussion to determine their validity as choices – what did students decide was part of the system?

Post-Video Materials

The first item below is connected to the first item in the pre-video materials. See the description there.

1. Here are some suggestions and comments for facilitating discussion of the sled handout on page A4:

- This picture has multiple problems. Once students start pointing them out, it may be good to keep track of them on the board and deal with them systematically.
- Some students may have drawn a diagram of the brother, rather than of the sled.
- Is the "Weight" the weight of the sled or of the brother?
- The non-tilted normal force is a classic mistake. It is probably worth taking a minute to underline the definition of "normal" as "perpendicular."

The two activities below are best suited for use in a discussion/recitation section. They can also be used by students outside of class who desire extra practice.

2. Team Practice

You will need at least one partner for this, and each of you will need paper and a pen or pencil. First, each of you will draw or describe (in writing) any sort of physical situation. Take no more than two minutes. When you are done, trade your description or drawing with a partner's. Now create a free body diagram for your partner's situation. When you are done, switch back and see if your partner drew what you would have expected.

If you are doing this at home, you can try to diagram situations that you find in videos online. Many sports or gymnastics videos are excellent for this purpose.

3. Choosing an Approach

Look through your textbook and choose a few homework problems that do not explicitly require a free body diagram. Decide whether one would be beneficial. If so, draw the diagram. If not, write a sentence as to why. You don't need to solve the entire problem. If you are working with a partner, check to see if you both agree.

4. A set of formative assessment questions can be found in the appendix (pages A5-1 through A5-5). There are also pre-made PowerPoint® slides for these questions in the "Clickers Post.pptx" file.

These questions work well with classroom response systems (clickers), but can also be used with a simple vote-by-hand-raise. When using these items, remember that they are discussion builders, not problems that the students need to answer correctly in order to get credit. Do not use these as test items.

Not all of the questions need to be used together, but more than one should be used. Each one uses the same physical setup (a block on a ramp with a pulley and weight), but with different lengths of forces.

Avoid giving answers to these questions! Students are capable of coming up with the answers through discussion and consideration; give them the time to do that rather than rushing in with the right answer. Let them argue about whether "moving" means velocity or acceleration.

Some of the diagrams are labeled, "These forces balance". Forces in the other diagrams do not balance. You can tell the students this; tricking them with arrow lengths is not the goal of the questions.

These questions are designed to pull out certain points of confusion:

- What direction does the friction force point?
- Does "motion" mean "velocity" or "acceleration" to the students?
- Can velocity and acceleration be in different directions?

Additional Resources

Going Further

Centripetal force is an important concept, and one that is often confusing for students. Because of both time constraints and the way in which the Physics 101 schedule is arranged, it was decided that centripetal force could not be treated properly in this video. The original script and slides for this section of the video are included in the "Going Further" folder for those faculty members who would like a little extra material to present when tackling this topic.

References

MIT's OpenCourseWare site includes an introduction to forces. It may be a good resource for students who want to learn more on their own.

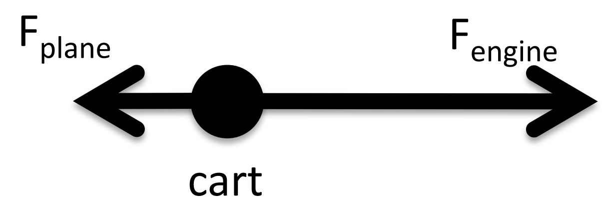
- Lewin, Walter. *8.01 Classical Mechanics, Fall 1999*. (Massachusetts Institute of Technology: MIT OpenCourseWare), http://ocw.mit.edu (Accessed 22 Dec, 2011). License: Creative Commons BY-NC-SA
- The videos stored at this location are particularly useful: http://ocw.mit.edu/courses/physics/8-01sc-physics-i-classical-mechanics-fall-2010/concept-of-force/

The following papers and journal articles may also be of use when researching student difficulties, best practices, and the educational use of free body diagrams.

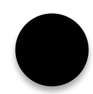
- Rosengrant, D., Van Heuvelen, A., Etkina, E. (2005) Free-body diagrams: Necessary or sufficient? *AIP Conference Proceedings 790*, 177-180. (This item was presented at the 2004 Physics Education Research Conference, whose proceedings were published in 2005.)
- Floresa, S., Kanimb, S., Kautzc, C. (2004) Student use of vectors in introductory mechanics. *American Journal of Physics 72*(4), 460-468.
- Van Heuvelen, A. (1991) Learning to Think like a Physicist: A review of research-based instructional strategies. *American Journal of Physics 59*(10), 891-897.
- Rosengrant, D., Van Heuvelen, A., Etkina, E. (2009) Do students use and understand free-body diagrams? *Physical Review Special Topics – Physics Education Research 5*(1), 010108 1-12.

Free-Body Diagram Handout #1

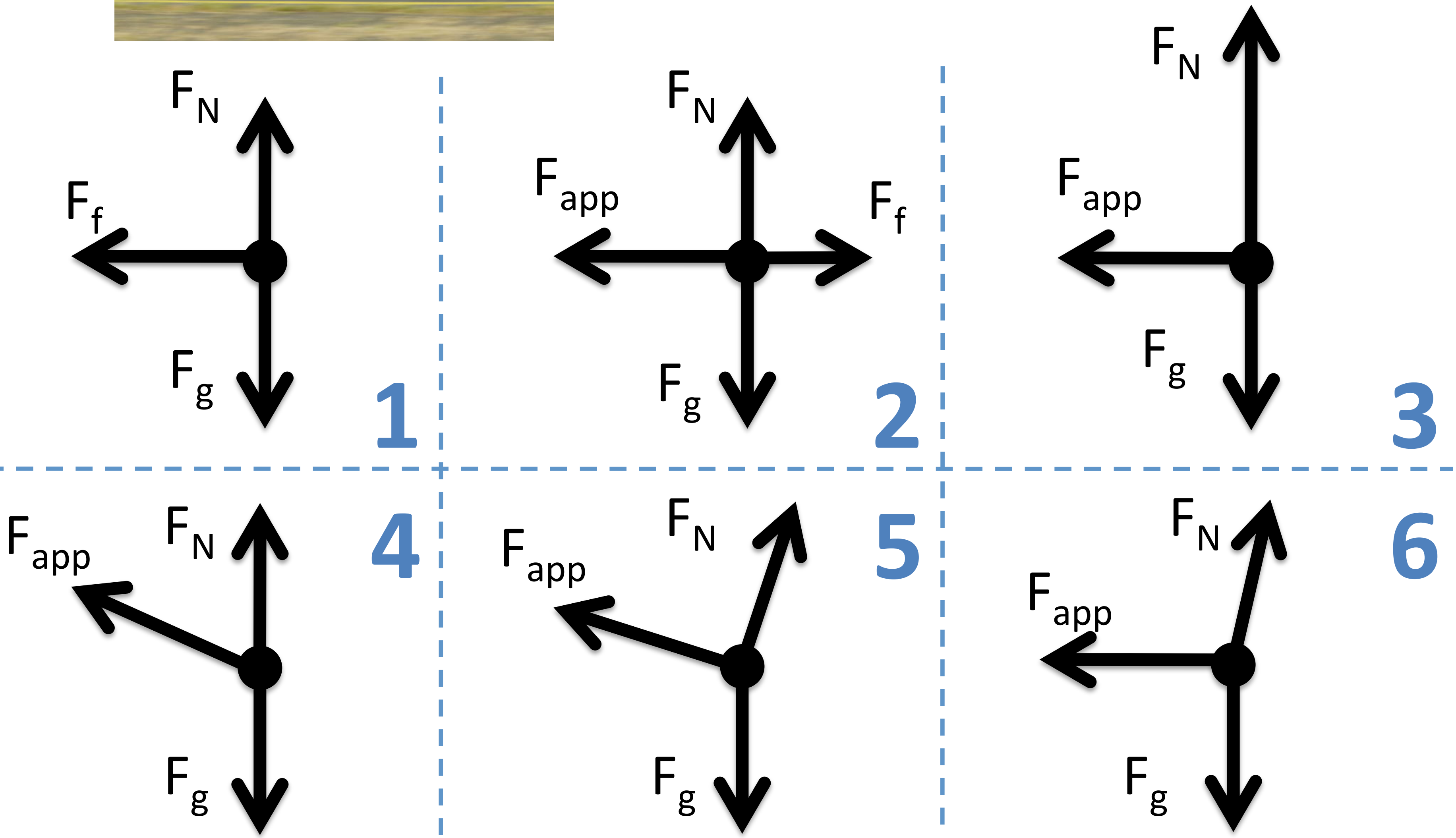
The cart pushing this plane is moving forward at constant velocity. What is wrong with the free body diagram of the cart below? Re-draw the diagram correctly. Be ready to defend your answer.



Draw Corrected Version Here:



Which Free Body Diagrams could properly represent this image?

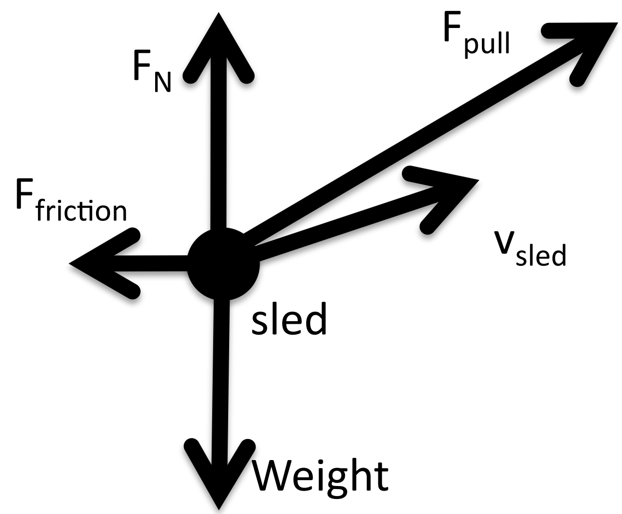


Which forces are present on the hot-air balloon in this image?

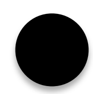
① Gravity
② A buoyant force
③ Weight
④ Air resistance
⑤ None of the above are necessarily present
⑥ Some other force

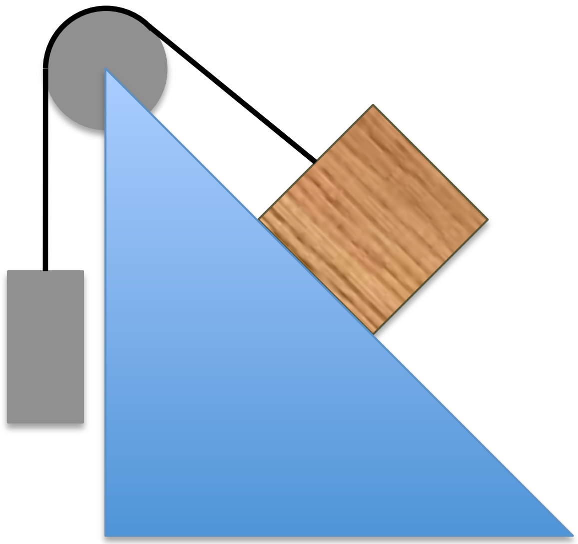
Free-Body Diagram Handout #2

The girl pulls her little brother uphill in a sled at constant velocity. What is wrong with the free body diagram of the sled below? Re-draw the diagram correctly. Be ready to defend your answer.

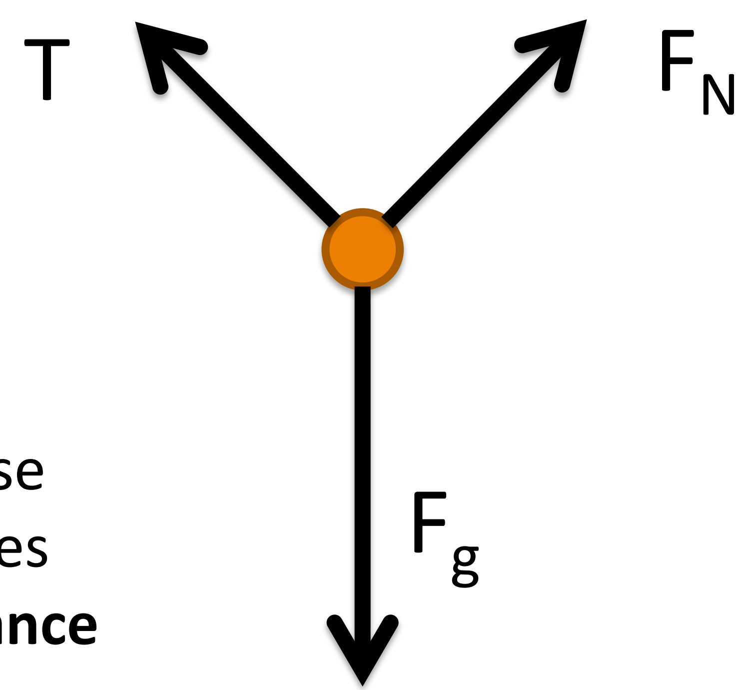


Draw Corrected Version Here:

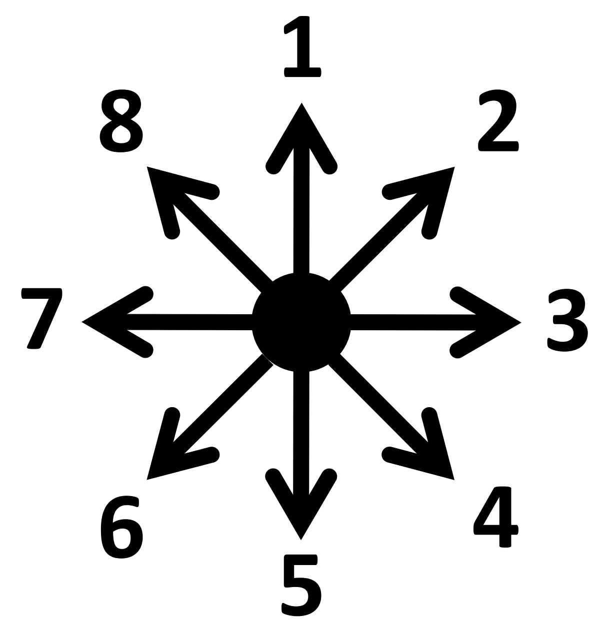




Given the free body diagram below, in what direction is the wooden block moving?

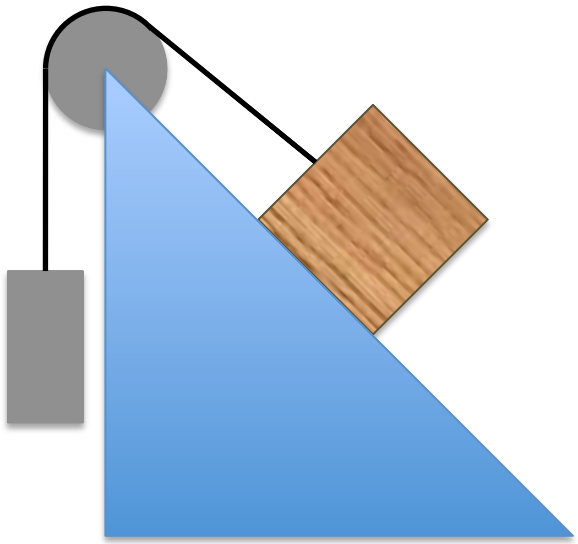


These forces **balance**



9 Not Moving

0 Can't Tell



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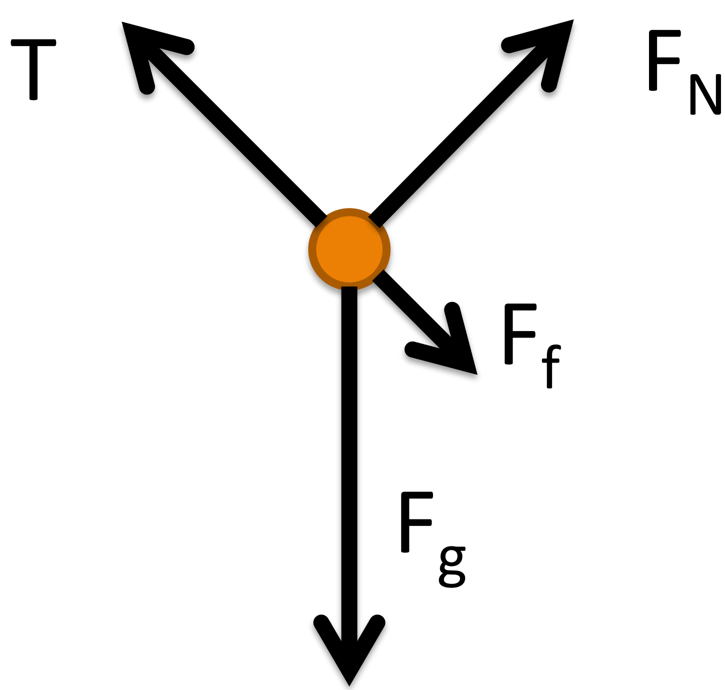

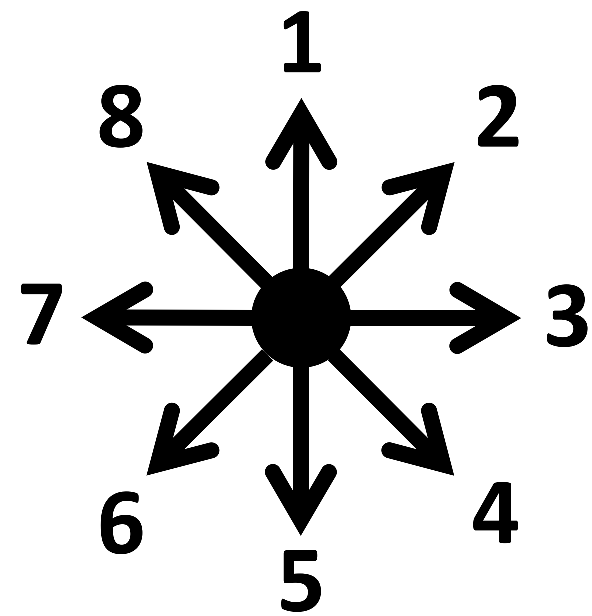

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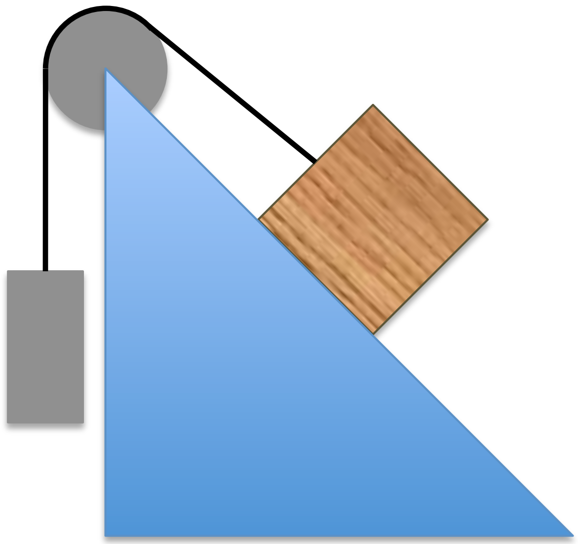

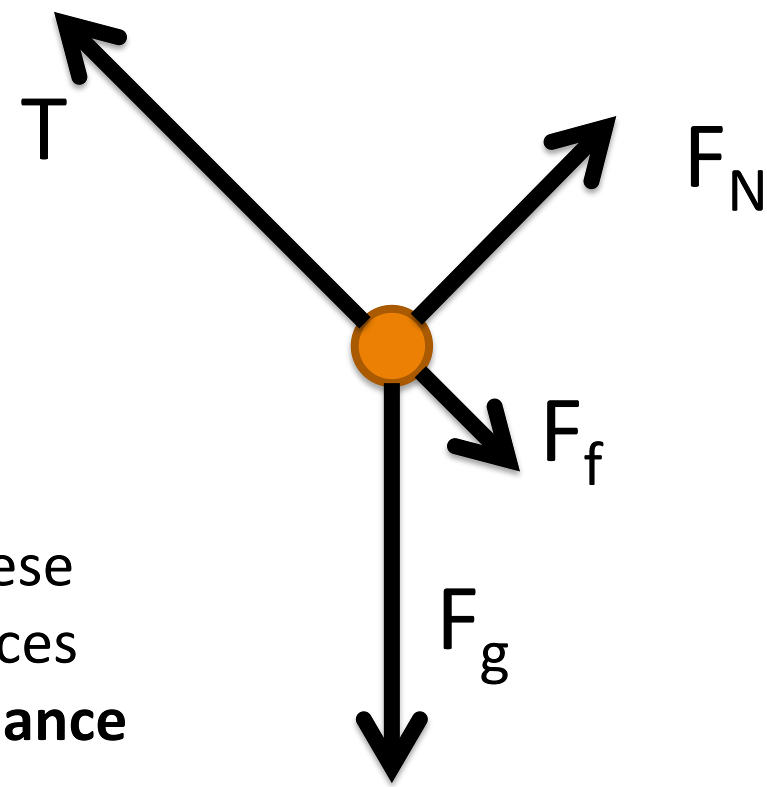

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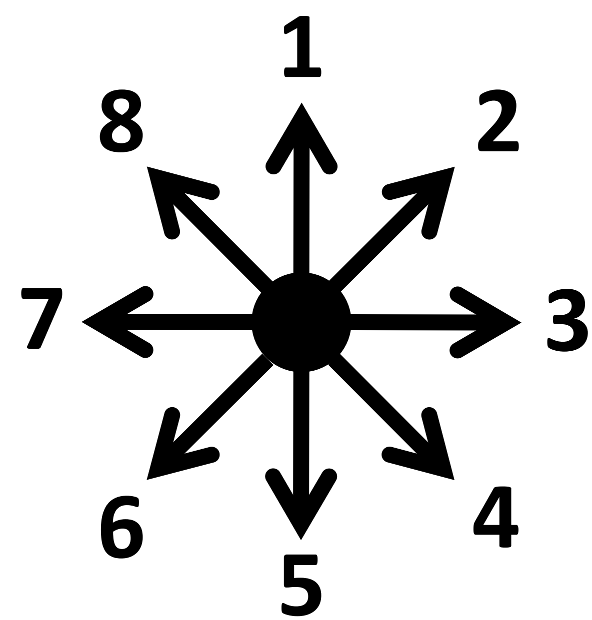

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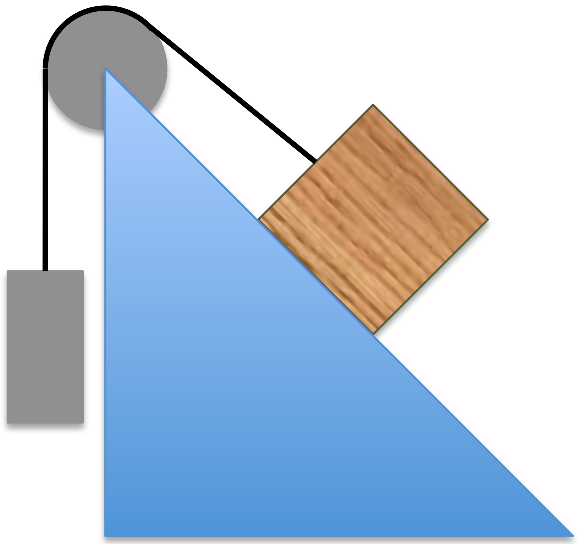

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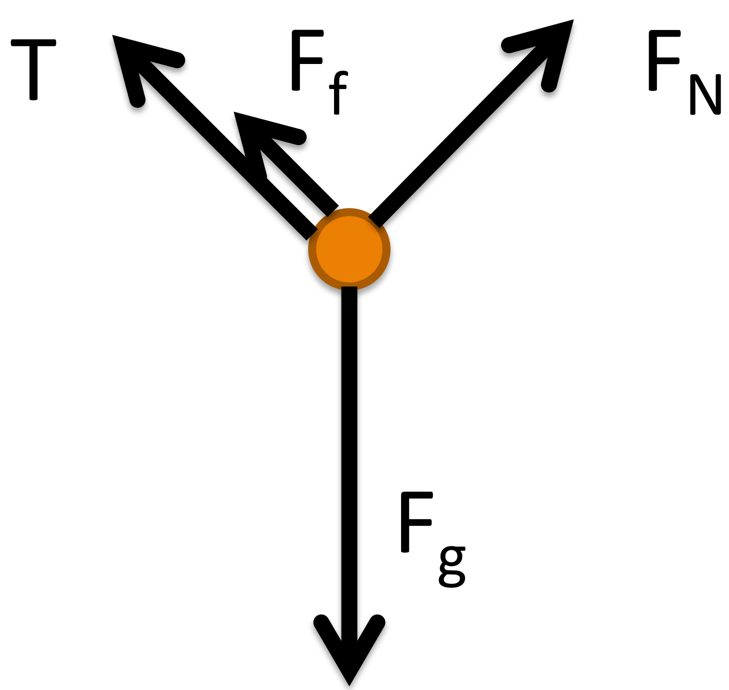

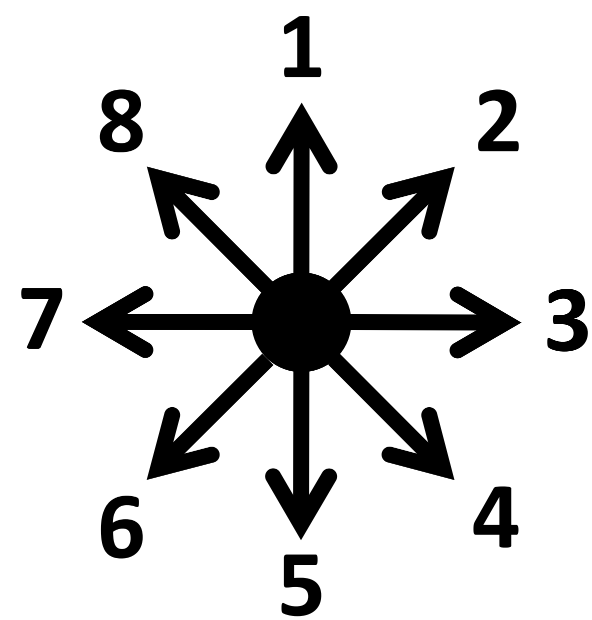

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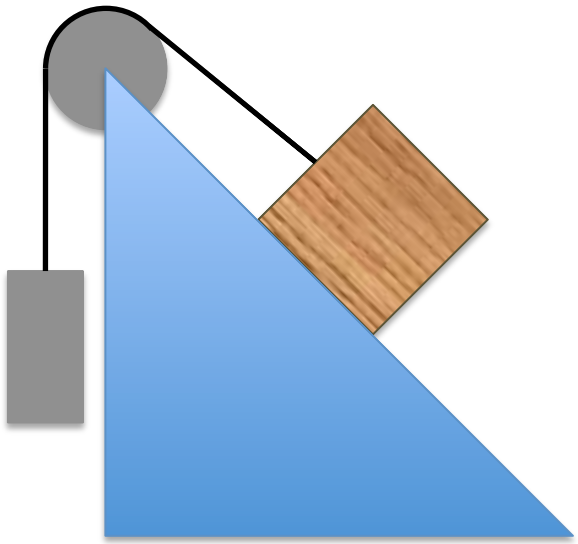

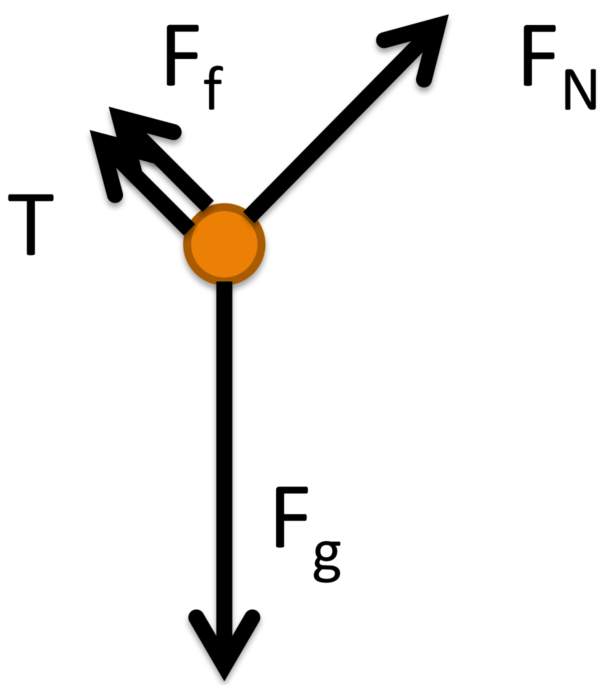

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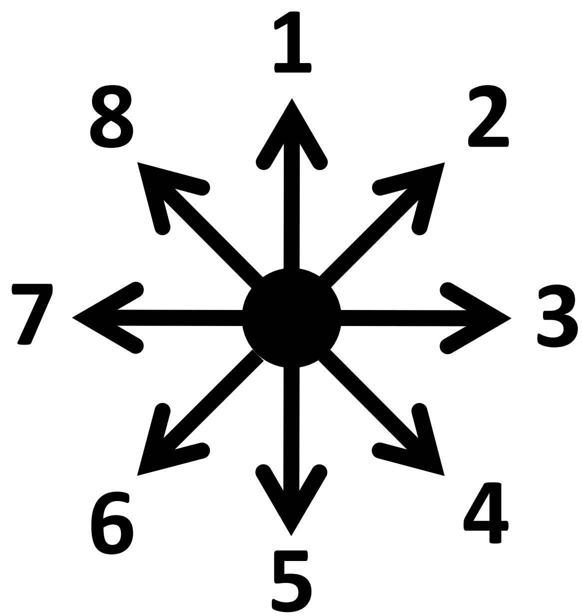

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