Gravity

Governing Rules 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, in lecture or discussion, in or after Lecture 40 or 41.
- Students should have been introduced to Newton's Law of Gravity. Exposure to Kepler's Laws is not necessary.

Key Information

Duration: 14:48
Narrator: Prof. Nergis Mavalvala
Materials Needed:
• paper
• pencil

Learning Objectives

After watching this video students will be able to:

- Recognize the three most common models of gravity and their equations.
- Analyze situations involving gravity in preparation for problem-solving.

Motivation

- While it is part of the Governing Rules series, this video also underscores the importance of viewing our equations and laws as representations and approximations of a phenomenon.
- Most videos on gravity tend to focus on a particular regime – near earth, Newtonian, or Einsteinian. Few include all three of the usual models.
- Most videos on gravity also lack any opportunity for student activity. The end of this video gives students a chance to practice analyzing problems and determining what would be needed for a solution.

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 the video, students will determine what quantities and equations would be needed to solve a gravity problem.

Video Highlights

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

Time	Feature	Comments
0:45	Instructor's introduction	Includes outline and learning objectives at 1:11.
2:02	Expressions for gravity	
2:32	Gravity near Earth	Includes elevator counterweights, counterbalanced trams, and piledriver examples.
4:10	Newton's gravity	Continues to 9:05. Includes a variety of examples, such as the shape of planets and their orbits.
5:40	Tides and tidal forces	Examples include tides on Earth and the tidal forces responsible for the Roche Limit.
7:04	Dark matter and the larger universe	A simulation of the universe at 8:22
9:05	General Relativity	Includes descriptions of black holes, gravitational lensing, and the cosmological constant. An animation of stars near the Milky Way's supermassive black hole appears at 10:03.
11:30	Wrap-up	
11:50	Second part begins	
12:24	Examples of problem analysis	One simple example and one complex example are included.
14:23	Problems to analyze	Four problems are shown, with the intention of students being assigned to groups and analyzing the problems.

Video Summary

The first half of this video describes gravitational phenomena based on three models of increasing complexity: gravity near Earth's surface, Newton's law of gravitation, and General Relativity. Each example is illustrated and connected to the model that best describes it. In the second half, students are asked to analyze a set of systems involving gravity. Students see examples, and analyze the information needed to describe the system fully.

Phys 101 Materials

Pre-Video Materials

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

1. Moon and Planet, page A1

This clicker question is intended to check for a variety of potential misconceptions about the action of gravity. The correct choices are 4 and 5. Students who select 2 or 7 may not have internalized Newton's First Law. Students who select 1 or 6 may be confusing force with torque or considering the rotation of the objects rather than the action of gravity. Students who select arrow 3 are likely to be considering the path of the object rather than the force that leads to that path.

2. Mass Dependence, pages A2-1 and A2-2

This pair of questions is aimed at bringing out students' level of comfort with Newton's Third Law, as well as their ability to compare vector magnitudes. Arguments should be elicited from the students, before the answer is given, as to why they made the selection they did.

On the first slide #5 is correct. Students often believe that less massive objects exert less force on more massive objects. There is also a common confusion about whether the arrow drawn on the object is the force *on* that object, or the force *from* that object. Beware the phrase "The force *of* the right-hand one" – it is often an indication that the student does not have a precise enough picture in his or her mind.

On the second slide, #3, 5, and 6 are all possibly correct selections. Students who choose #4 may be imagining that the objects are more compressed, therefore denser, therefore heavier.

3. Distance Dependence, page A3

This question involves the straightforward application of Newton's Law of Gravity. #4 is in fact correct: the objects are twice as far apart, and the arrows are one quarter their previous length.

4. Floating in Space, page A4

The answer to this classic question depends on the specific definition of "weight." Collect responses first, and use the results to spark a discussion.

Students who believe that "weight is the reading on a scale" should feel confident choosing #3. Those who believe that "weight is an object's mass times the acceleration due to gravity" should instead choose #4, unless they believe that there is no gravity in near-Earth orbit. (If students persist in that belief, have them calculate the strength of graivty at the 350km altitude that the International Space Station typically maintains.)

5. Gravitational Potential, page A5

Answers #5 and #6 are fairly obviously incorrect. Answers #1 and #4 follow the opposite of the usual sign convention. If students view M and m as point masses, they are likely to choose #2; if they consider them as real objects, #3 is a more appropriate choice.

Post-Video Materials

6. Three questions are included on pages A6-1 through A6-3, and in the Questions.pptx file. Each is similar to the questions at the end of the Gravity video (which are also included in the Problem Slide.pptx file). The goal of these questions is to stimulate classroom discussion of how problems can be solved; none of them actually needs to be solved in total.

Each of these problems has at least one complicating factor; clever students will no doubt find more. The projectile problem involves not only knowledge of the Earth's curvature, but must also take into account the changing gravity as the projectile moves farther from the center of the planet. The collapse of interstellar clouds depends not only on the density and size of the cloud, but also on its temperature (i.e. the kinetic energy of the particles involved), an item that students may not consider. Finally, the sun problem requires some use of centripetal forces, as well as the questions of whether the sun can be treated as a collection of fluid.

Remember that the goal of these problems is not to *answer* questions, but to *raise* them.

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Additional Resources

Going Further

The Going Further folder contains a file entitled "General Relativity.pdf", which describes equations for the deflection of light and gravitational time dilation, with a few problems for each. Both phenomena can be described with trigonometry-level mathematics. Also in the folder are the light-bending diagram shown in the .pdf file, and a telescope image of gravitational lensing that is used in a problem about the deflection of light.

Unit conversion from the CGS system can be tricky for freshmen. Some practice or assistance is recommended.

For students who are more mathematically inclined, the following reference derives the equations for planetary orbits using differential equations:

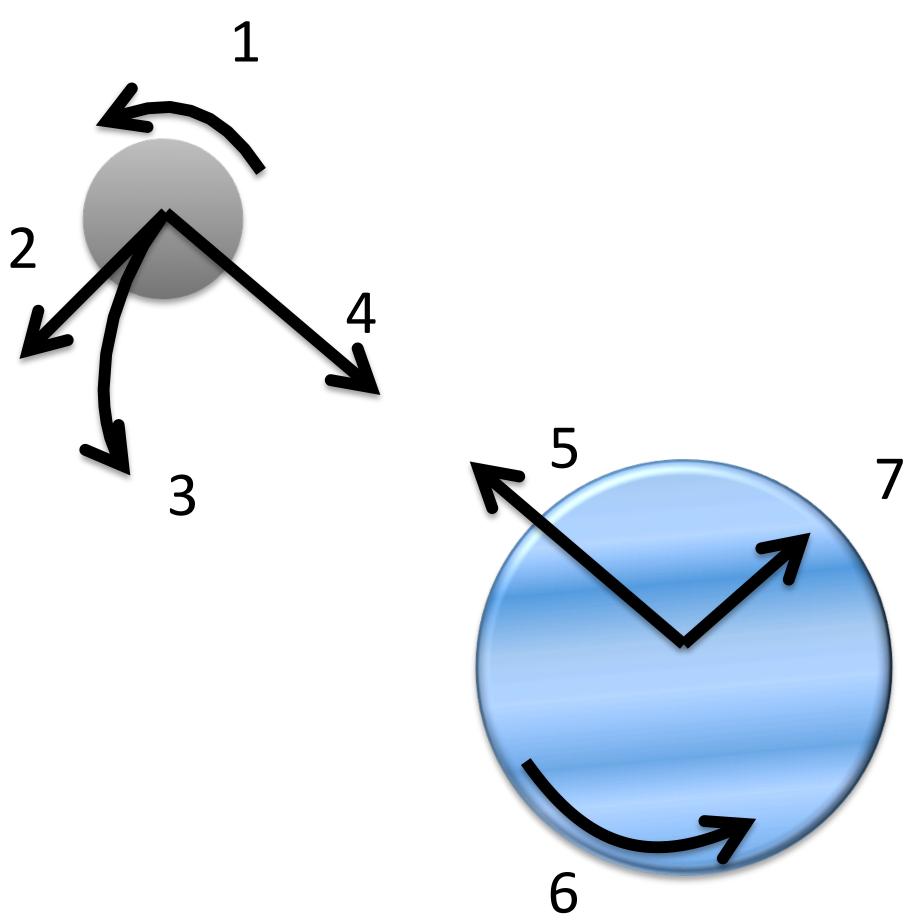
- Acheston, D. (1997) *From Calculus to Chaos.* New York: Oxford University Press Inc.

References

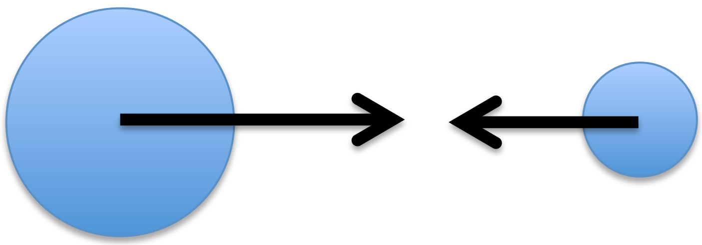
The first reference is a broad overview of gravity-related educational research, including items from grade school through the college level. The remaining papers deal with individual topics related to gravity, focusing on students' likely preconceptions about gravity.

- Kavanagh, C., Sneider, C. (2006) Learning about Gravity II. Trajectories and Orbits: A Guide for Teachers and Curriculum Developers. Astronomy Education Review, 5 (2), 53-102, doi:http://dx.doi.org/10.3847/AER2006019
- Zeilik, M., & Morris, V. (2003). An Examination of Misconceptions in an Astronomy Course for Science, Mathematics, and Engineering Majors. Astronomy Education Review, 2 (1), 101, doi:10.3847/AER2003005
- Yu, K.C., Sahami, K., & Denn, G. (2010). Student Ideas about Kepler's Laws and Planetary Orbital Motions. Astronomy Education Review, 9 (1), 010108, doi:10.3847/AER2009069
- Graham, T. & Berry, J. (1993). Students' Intuitive Understanding of Gravity. *International Journal of Mathematical Education in Science and Technology, 24*(3) 473-478
- Treagust, D. F. and Smith, C. L. (1989), Secondary Students' Understanding of Gravity and the Motion of Planets. School Science and Mathematics, 89: 380–391. doi: 10.1111/j.1949-8594.1989.tb11935.x

Here we see a moon orbiting its planet counterclockwise.
Which arrows represent the forces on these two objects?
Choose all that apply.



The arrows on the diagrams below indicate forces.
Which diagram is correct for the two objects shown?
The larger object is twice as massive.

1


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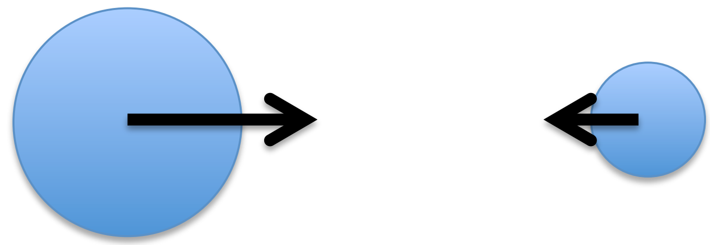

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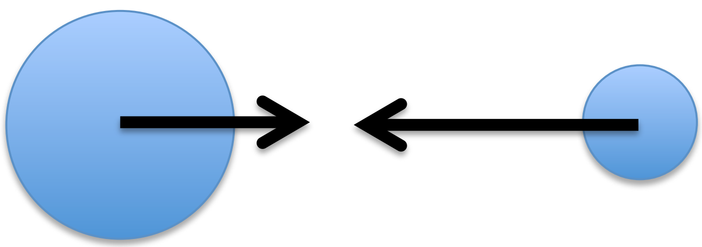

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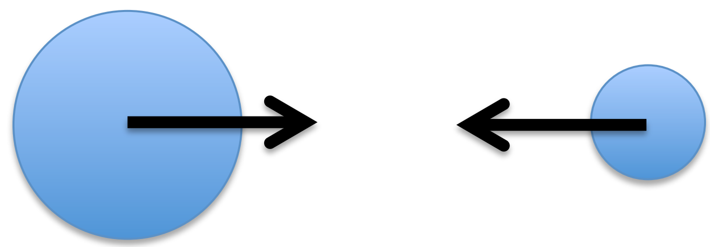

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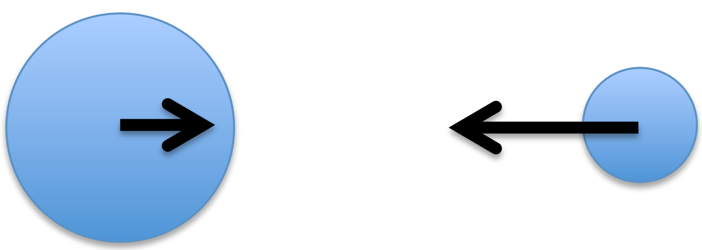

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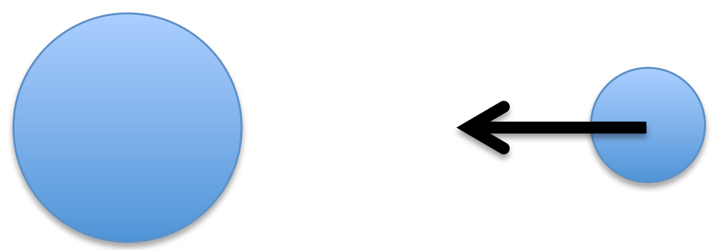
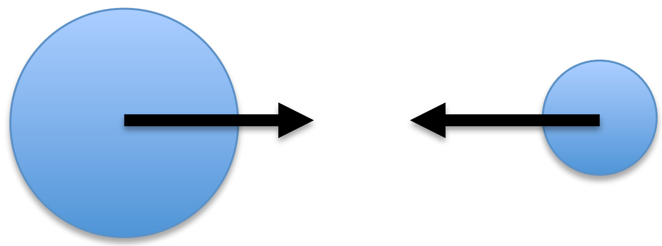
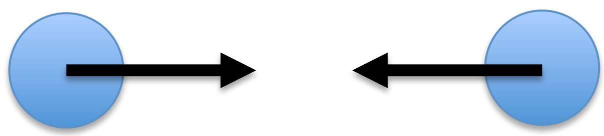




If the force vectors drawn to the left are correct, select all correct diagrams from the list below. You may assume that larger objects have a larger mass.

1



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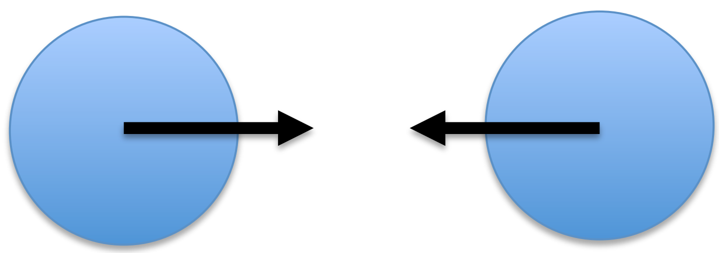

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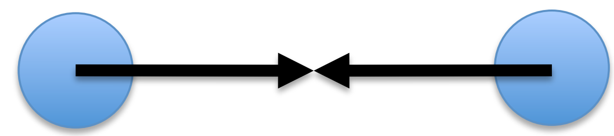

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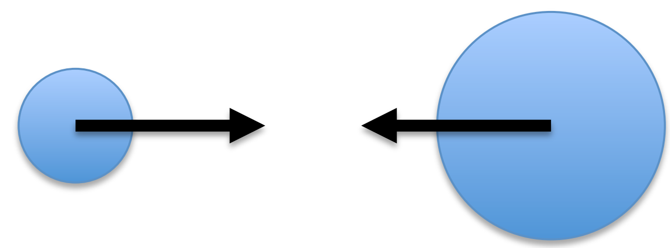

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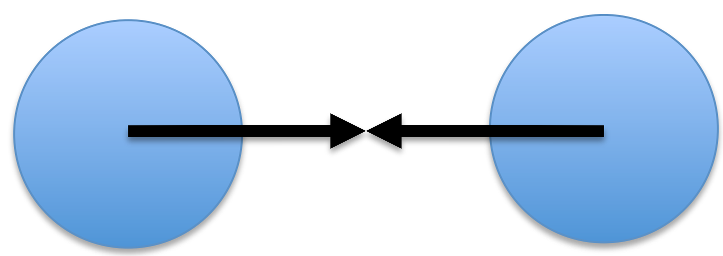
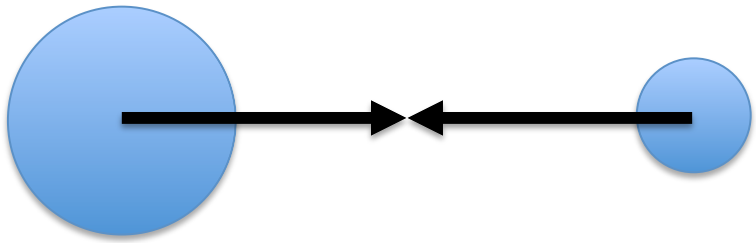
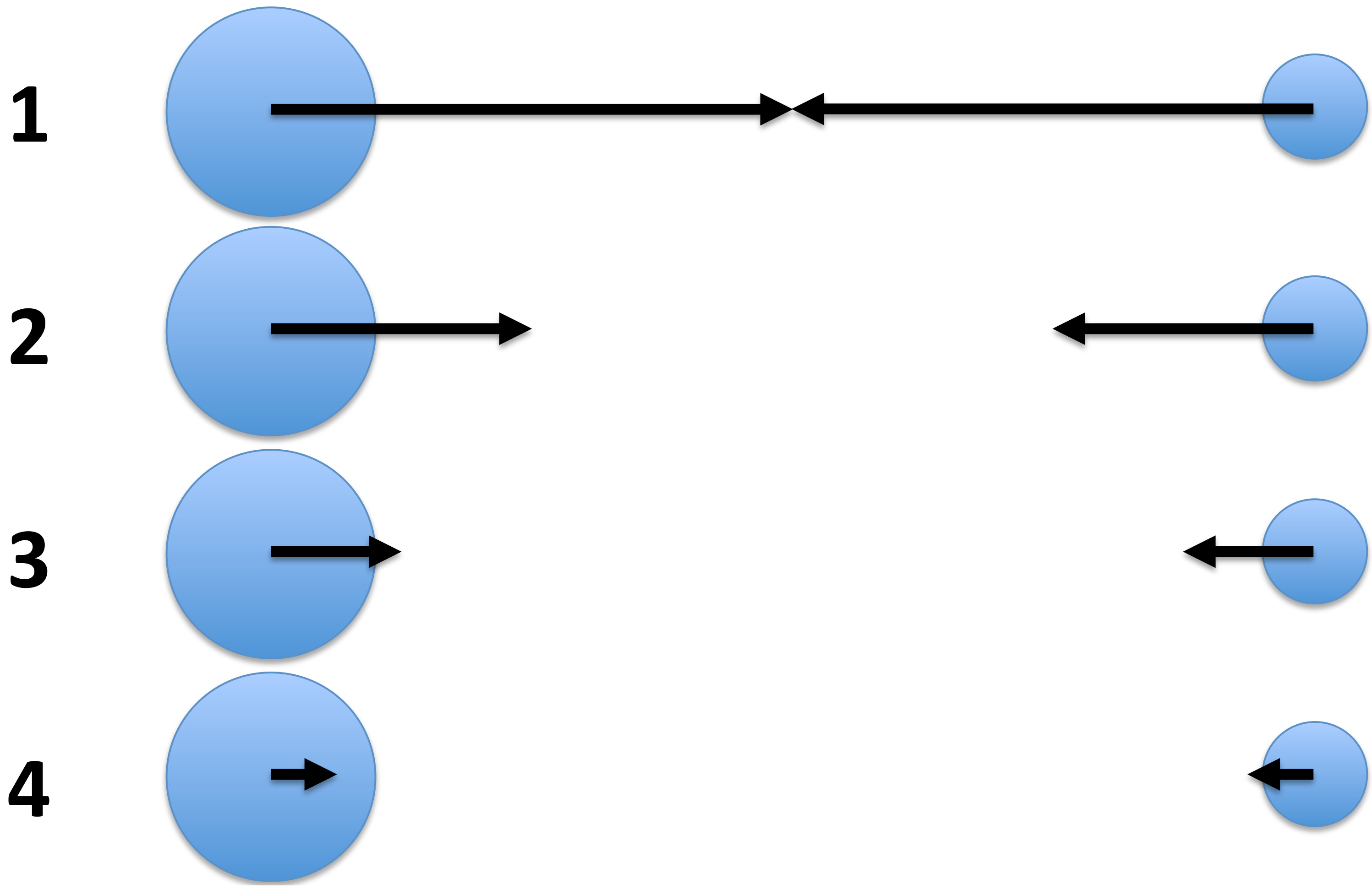




If the force vectors drawn to the left are correct for the distance shown, select the correct diagram from the list below given the new distance.

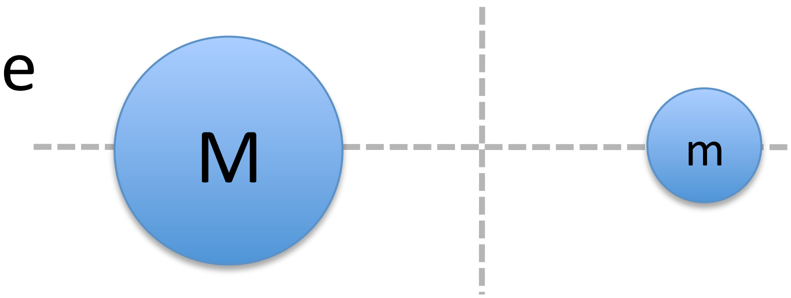


An astronaut floats inside an orbiting space station. Which of the following are true? Select all that apply.

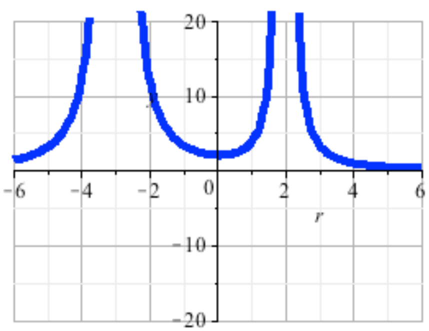
① No forces act on the astronaut.
② The astronaut has no mass.
③ The astronaut has no weight.
④ None of these are true

Photo: Astronaut Karen Nyberg, NASA, USA

Identify the correct graph for the gravitational potential in the system shown to the right.



1



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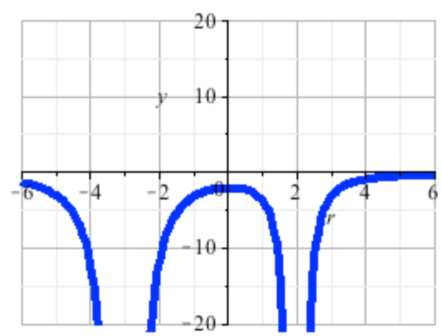

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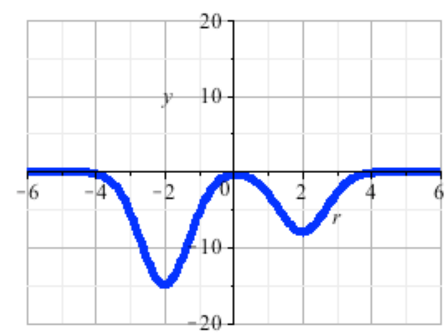

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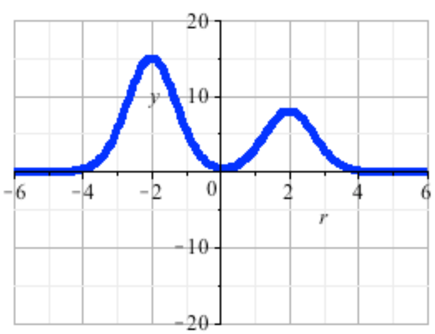

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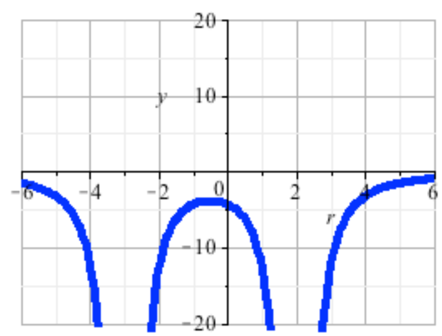

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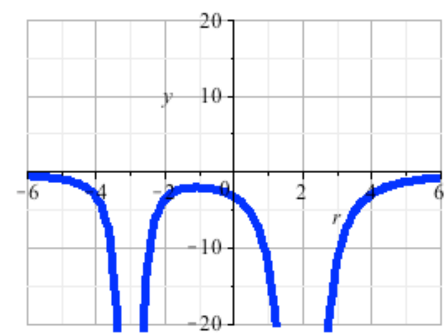
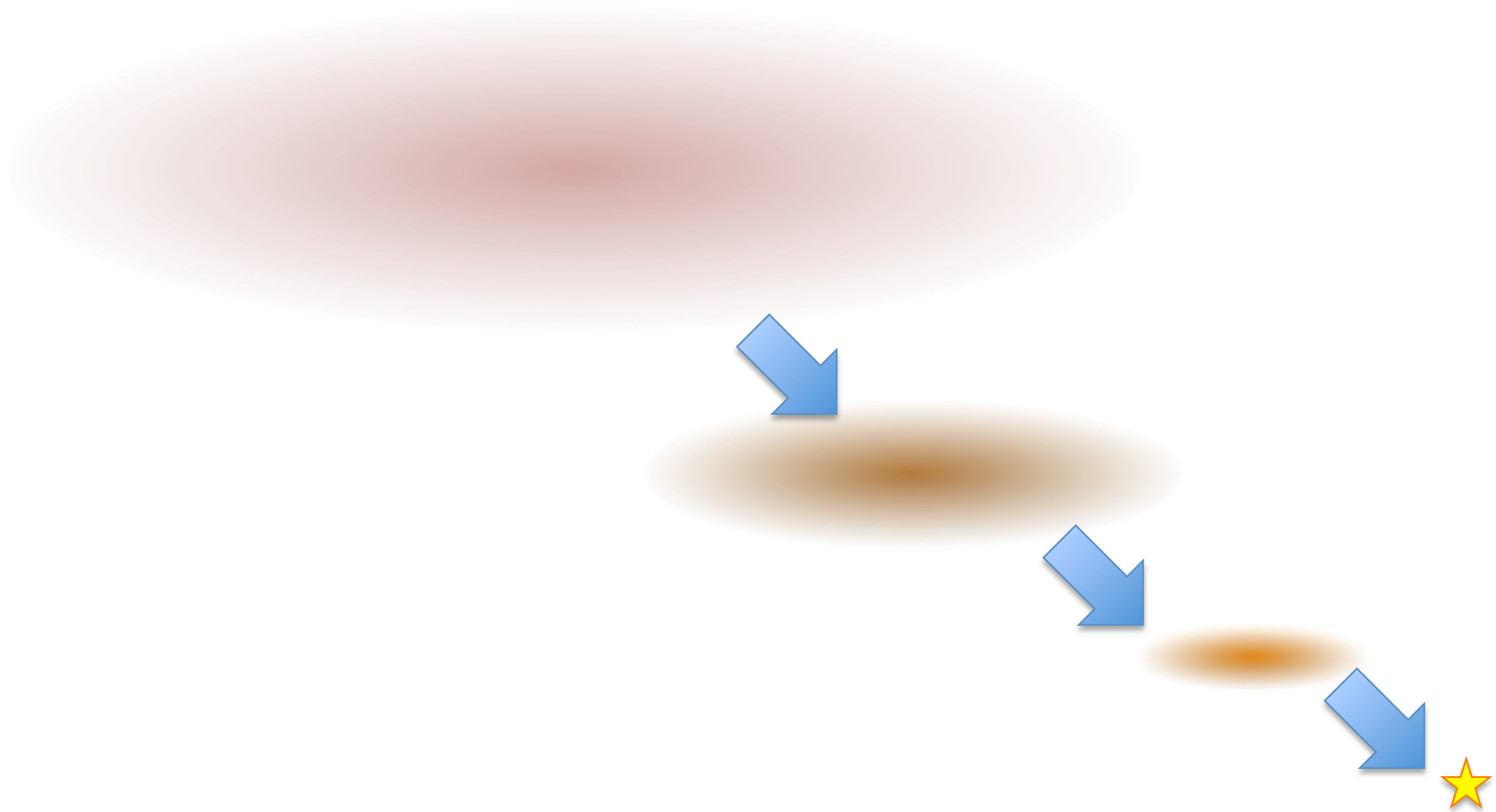


A cannon fires a shot at very high velocity, such that the cannonball follows the trajectory shown in the picture.

What information would you need in order to determine the amount of time required for the cannonball to hit the Earth?

Stars are formed through the gravitational collapse of gas clouds. What information would you need in order to determine how long does this process takes?



The Sun is not a perfect sphere; it is deformed as shown in the illustration below. What information would you need in order to determine the amount of deformation?