Complete Solutions and Answers

for

Introductory Physics

by

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Note: There is an errata page on our website
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Chapter 1 Exercises

Study Questions

1. Distinguish between theories and hypotheses.

A theory is a mental model or explanatory system that attempts to explain the scientific data in a sphere of knowledge. Theories enable us to make new predictions about the natural world. A hypothesis is a prediction based on a theory about what will happen in an experiment. A hypothesis is tested by conducting an experiment that either confirms or disconfirms the theory upon which it is based.

2. Explain why a single experiment can never prove or disprove a theory.

First, theories are models and thus are never proved or disproved at all. Instead they get stronger or weaker based on their ability to explain experimental data.

Because an effective experiment is difficult to perform, the experiment must be replicated by several different experimental teams for any experimental outcome to be regarded as fact. There are many reasons a hypothesis might not be confirmed by a particular experiment, including flaws in the experiment, an incorrect understanding of the theory upon which the hypothesis is based (and thus a faulty hypothesis), or inaccurate or imprecise measurements during the experiment.

3. Explain how an experiment can still provide very valuable data, even if the hypothesis under test is not confirmed.

If an experiment cannot confirm the hypothesis under test, the scientist must first double-check the experiment for flaws and re-examine his or her understanding of the theory to ensure that the hypothesis is a correct statement of what the theory says will happen. But an experiment that is replicated again and again by several different experimental teams with the same results and still cannot confirm the hypothesis under test provides very valuable data, namely a new fact. This new fact is not consistent with the prevailing theory.

The theory may be able to be altered to account for the new fact. But if the theory simply cannot account for the new fact, then the theory has a weakness. If enough of these weaknesses accumulate, then over a long period of time (often decades, or even centuries) the theory might eventually be replaced with a better theory.

4. Explain the difference between truth and facts, and describe the sources of each.

Truth is the way things really are and cannot change. Truth may be known by direct observation, by valid reasoning from true premises or by divine revelation. Revelation may be either Special Revelation (the book of God's Word, the Bible) or General Revelation (the book of God's Works, nature). Truth is true for all time and all people. Scientific facts, on the other hand, are propositions that are supported by a great deal of evidence. They are discovered by observation, experiment, and by making inferences from what we observe or the results of our experiments. Facts are considered to be correct so far as we know. However, facts can change when new information becomes known.

5. State the two primary characteristics of a theory.

A successful scientific theory must account for most or all the known facts, tying them together in a single explanation. Secondly, a successful theory must lead to the formation of new hypotheses that can be tested.

6. Does a theory need to account for all known facts? Why or why not?

No. A useful scientific theory must account for most of the related facts, but no theory ever explains everything perfectly. There are always phenomena that theories do not adequately explain. Still, scientists continue their work in a field hoping eventually to have a theory that explains as many of the facts as possible.

7. It is common to hear people say, "I don't accept that; it's just a theory." What is the error in a comment like this?

In science, theories are all we have. All scientific knowledge is theoretical, or theory-based. There is no scientific statement that can be made apart from the theoretical framework that explains the statement. Theories take a long time to develop and support with experimental facts, and they should not be dismissed simply because they are theories. Theories are the glory of science.

Comment: This discussion about the nature of science and the distinction between the terms truth, fact, and theory, is essential in training our students well and equipping them to live "purposefully and intelligently in the service of God and man," as one school's mission statement puts it. The misuse of the term "theory," by both Christians and non-Christians alike, is one of the primary elements fueling cultural controversies over science in our country. Christian schools have a very important responsibility in this regard: to instruct students on what theories are, how they develop, and the central role they play in all scientific research. For additional resources on responsibly addressing this issue see our book *Teaching Science so that Students Learn Science*.

8. Distinguish between facts and theories.

A theory is a mental model that explains most or all of the facts in a certain sphere of knowledge. A theory becomes stronger by producing successful predictions that are confirmed by experiment. A theory will be gradually weakened if new facts resulting from experiments turn out to be inconsistent with the theory. Facts are propositions supported by a lot of experimental evidence that are correct so far as we know.

9. Distinguish between explanatory variables, response variables, and lurking variables.

The explanatory variable is the variable that is deliberately manipulated by the researchers. As it is manipulated, the researchers monitor the effect this variation has on the response variable. Usually only one explanatory variable is manipulated at a time so that researchers can definitively tell what its effect is on the response variable. A lurking variable is a variable that is affecting the response variable without the researchers being aware of it. Researchers have to study their experimental projects very carefully to minimize the possibility of lurking variables affecting their results.

10. Why do good experiments that seek to test some kind of new treatment or therapy include a control group?

When experimenting on people to try new therapies or medications, researchers divide the patients involved in the study into two groups: the control group and the experimental group. The control group receives no treatment or some kind of standard treatment. The experimental group receives the new treatment being tested. The results of the experimental group are assessed by comparing them to the control group.

11. Explain specifically how the procedure students followed in the Pendulum Experiment satisfies every step of the "scientific method."

The eight steps of the Scientific Method are below, along with explanations of how the procedure in the Pendulum Lab followed these steps.

1. State the problem. In our class discussion, we suggested possibilities for explanatory variables that could affect the period of a pendulum. We identified the weight, the length of the string, and the starting angle from which the pendulum is released as the three possible explanatory variables.
2. Research the problem. In teams, we discussed the three possible explanatory variables and considered our own experience and knowledge to determine which affect the period of a pendulum.
3. Form a hypothesis. We formed a team hypothesis and documented it in our lab journals.
4. Conduct an experiment. The team tested these three explanatory variables by manipulating one variable while keeping the other two variables constant.
5. Collect data. During the experiment, we recorded all experimental results in our lab journals. We had four tables of data in all, which included the results from 24 separate trials.
6. Analyze the data. After the experiment, we reviewed the data as a team and discussed which potential explanatory variables affected the period of the pendulum and which did not.
7. Form a conclusion. In our team discussion, we reached a conclusion and afterwards documented it in our lab reports.
8. Repeat the work. During the experiment, we repeated each of the different combinations of variables three times to ensure good, consistent data. We also followed this step by comparing our data with those of other groups.

12. This chapter argues that scientific facts should not be regarded as true. Someone might question this and ask, If they aren't true, then what are they good for? Develop a response to this question?

Scientific facts, though not truth claims, are also important knowledge and are correct so far as we know. They are essential to understanding the natural world around us. Scientific facts allow us to develop theories and make discoveries that enable us to better appreciate, use and steward our planet.

13. Explain what a model is, and why theories are often described as models.

A model is a representation of something else. The model is used to explain how the thing that it represents works. The more accurate the model, the more useful it is. A theory is a model, because it is a representation of how part of the world works.

14. Consider an experiment that does not deliver the result the experimenters expect. In other words, the result is negative because the hypothesis is not confirmed. There are many reasons why this might happen. Consider each of the following elements of the Cycle of Scientific Enterprise. For each one, describe how it might be the driving factor that results in the experiment's failure to confirm the hypothesis.

a. the experiment

The experiment may have been flawed. For example, the equipment might not have been working properly, the calculations may have been incorrect, or the measurement instruments may not have been accurate or precise enough to provide meaningful data.

b. the hypothesis

The hypothesis may have been based on an incorrect understanding of the theory. Maybe the experimenters did not understand the theory well enough, and maybe the hypothesis was not a correct statement of what the theory says will happen.

c. the theory

Finally, there could be a problem with the theory itself. Perhaps the theory can be altered to account for the new fact that the experiment demonstrated, or maybe the theory simply cannot account for the new fact and it has a weakness.

15. Identify the explanatory and response variables in the Pendulum Lab, and identify two realistic possibilities for ways the results may be influenced by lurking variables.

The explanatory variables in the Pendulum Lab were the weight, the length of the string, and the starting angle from which the pendulum is released. The response variable is the period of the pendulum. The results may have been affected by lurking variables such as air friction, moving air in the room, or vibrations/movements at the location where the top of the pendulum was attached.

Chapter 2 Exercises

Unit Conversions

1.

$$1{,}750\ \text{m}\cdot\frac{100\ \text{cm}}{1\ \text{m}}\cdot\frac{1\ \text{in}}{2.54\ \text{cm}}\cdot\frac{1\ \text{ft}}{12\ \text{in}}=5{,}740\ \text{ft}$$

2.

$$3.54\ \text{g}\cdot\frac{1\ \text{kg}}{1000\ \text{g}}=0.00354\ \text{kg}$$

3.

$$41.11\ \text{mL}\cdot\frac{1\ \text{L}}{1000\ \text{mL}}=0.04111\ \text{L}$$

4.

$$7\times10^{8}\ \text{m}\cdot\frac{100\ \text{cm}}{1\ \text{m}}\cdot\frac{1\ \text{in}}{2.54\ \text{cm}}\cdot\frac{1\ \text{ft}}{12\ \text{in}}\cdot\frac{1\ \text{mi}}{5{,}280\ \text{ft}}=4\times10^{5}\ \text{mi}$$

5.

$$1.5499\times10^{-12}\ \text{mm}\cdot\frac{1\ \text{m}}{1000\ \text{mm}}=1.5499\times10^{-15}\ \text{m}$$

6.

$$750\ \text{cm}^3\cdot\frac{1\ \text{mL}}{1\ \text{cm}^3}\cdot\frac{1\ \text{L}}{1000\ \text{mL}}\cdot\frac{1\ \text{m}^3}{1000\ \text{L}}=7.5\times10^{-4}\ \text{m}^3$$

7.

$$2.9979\times10^{8}\ \frac{\text{m}}{\text{s}}\cdot\frac{100\ \text{cm}}{1\ \text{m}}\cdot\frac{1\ \text{in}}{2.54\ \text{cm}}\cdot\frac{1\ \text{ft}}{12\ \text{in}}=9.836\times10^{8}\ \frac{\text{ft}}{\text{s}}$$

8.

$$168\ \text{hr}\cdot\frac{60\ \text{min}}{1\ \text{hr}}\cdot\frac{60\ \text{s}}{1\ \text{min}}=605{,}000\ \text{s}$$

9.

$$5{,}570\ \frac{\text{kg}}{\text{m}^3}\cdot\frac{1000\ \text{g}}{1\ \text{kg}}\cdot\frac{1\ \text{m}^3}{1000\ \text{L}}\cdot\frac{1\ \text{L}}{1000\ \text{mL}}\cdot\frac{1\ \text{mL}}{1\ \text{cm}^3}=5.57\ \frac{\text{g}}{\text{cm}^3}$$

10.

$$45\ \frac{\text{gal}}{\text{s}}\cdot\frac{3.786\ \text{L}}{1\ \text{gal}}\cdot\frac{1\ \text{m}^3}{1000\ \text{L}}\cdot\frac{60\ \text{s}}{1\ \text{min}}=1.0\times10^{1}\ \frac{\text{m}^3}{\text{min}}$$

11.

$$600{,}000\ \frac{\text{ft}^3}{\text{s}}\cdot\frac{(0.3048\ \text{m})^3}{1\ \text{ft}^3}\cdot\frac{1000\ \text{L}}{1\ \text{m}^3}\cdot\frac{60\ \text{s}}{1\ \text{min}}\cdot\frac{60\ \text{min}}{1\ \text{hr}}=6\times10^{10}\ \frac{\text{L}}{\text{hr}}$$

12.

$$5{,}200\ \text{mL}\cdot\frac{1\ \text{L}}{1000\ \text{mL}}\cdot\frac{1\ \text{m}^3}{1000\ \text{L}}=5.2\times10^{-3}\ \text{m}^3$$

13.

$$5.65\times10^2\ \text{mm}^2\cdot\frac{1\ \text{cm}}{10\ \text{mm}}\cdot\frac{1\ \text{cm}}{10\ \text{mm}}\cdot\frac{1\ \text{in}}{2.54\ \text{cm}}\cdot\frac{1\ \text{in}}{2.54\ \text{cm}}=0.876\ \text{in}^2$$

14.

$$32.16\ \frac{\text{ft}}{\text{s}^2}\cdot\frac{12\ \text{in}}{1\ \text{ft}}\cdot\frac{2.54\ \text{cm}}{1\ \text{in}}\cdot\frac{1\ \text{m}}{100\ \text{cm}}=9.802\ \frac{\text{m}}{\text{s}^2}$$

15.

$$5.001\ \frac{\mu\text{g}}{\text{s}}\cdot\frac{1\ \text{g}}{10^6\ \mu\text{g}}\cdot\frac{1\ \text{kg}}{1000\ \text{g}}\cdot\frac{60\ \text{s}}{1\ \text{min}}=3.001\times10^{-4}\ \frac{\text{kg}}{\text{min}}$$

16.

$$4.771\ \frac{\text{g}}{\text{mL}}\cdot\frac{1\ \text{kg}}{1000\ \text{g}}\cdot\frac{1000\ \text{mL}}{1\ \text{L}}\cdot\frac{1000\ \text{L}}{1\ \text{m}^3}=4{,}771\ \frac{\text{kg}}{\text{m}^3}$$

17.

$$13.6\ \frac{\text{g}}{\text{cm}^3}\cdot\frac{1000\ \text{mg}}{1\ \text{g}}\cdot\frac{100\ \text{cm}}{1\ \text{m}}\cdot\frac{100\ \text{cm}}{1\ \text{m}}\cdot\frac{100\ \text{cm}}{1\ \text{m}}=1.36\times10^{10}\ \frac{\text{mg}}{\text{m}^3}$$

18.

$$93{,}000{,}000\ \text{mi}\cdot\frac{5280\ \text{ft}}{1\ \text{mi}}\cdot\frac{0.3048\ \text{m}}{1\ \text{ft}}\cdot\frac{100\ \text{cm}}{1\ \text{m}}=1.5\times10^{13}\ \text{cm}$$

19.

$$65\ \frac{\text{mi}}{\text{hr}}\cdot\frac{5{,}280\ \text{ft}}{1\ \text{mi}}\cdot\frac{0.3048\ \text{m}}{1\ \text{ft}}\cdot\frac{1\ \text{hr}}{60\ \text{min}}\cdot\frac{1\ \text{min}}{60\ \text{s}}=29\ \frac{\text{m}}{\text{s}}$$

20.

$$633\ \text{nm}\cdot\frac{1\ \text{m}}{10^9\ \text{nm}}\cdot\frac{100\ \text{cm}}{1\ \text{m}}\cdot\frac{1\ \text{in}}{2.54\ \text{cm}}=2.49\times10^{-5}\ \text{in}$$

21.

$$0.05015 \cdot 3.00 \times 10^{8}\ \frac{\text{m}}{\text{s}} \cdot \frac{60\ \text{s}}{1\ \text{min}} \cdot \frac{60\ \text{min}}{1\ \text{hr}} \cdot \frac{1\ \text{ft}}{0.3048\ \text{m}} \cdot \frac{1\ \text{mi}}{5{,}280\ \text{ft}} = 3.37 \times 10^{7}\ \frac{\text{mi}}{\text{hr}}$$

Motion Exercises

1. A train travels 25.1 miles in 0.50 hr. Calculate the velocity of the train.

$$d = 25.1\ \text{mi} \cdot \frac{5{,}280\ \text{ft}}{1\ \text{mi}} \cdot \frac{0.3048\ \text{m}}{1\ \text{ft}} = 4.04 \times 10^{4}\ \text{m}$$

$$t = 0.50\ \text{hr} \cdot \frac{60\ \text{min}}{1\ \text{hr}} \cdot \frac{60\ \text{s}}{1\ \text{min}} = 1{,}800\ \text{s}$$

$$v = ?$$

$$d = vt$$

$$v = \frac{d}{t} = \frac{4.04 \times 10^{4}\ \text{m}}{1{,}800\ \text{s}} = 22\ \frac{\text{m}}{\text{s}}$$

2. Convert your answer from the previous problem to km/hr.

$$22\ \frac{\text{m}}{\text{s}} \cdot \frac{1\ \text{km}}{1000\ \text{m}} \cdot \frac{60\ \text{s}}{1\ \text{min}} \cdot \frac{60\ \text{min}}{1\ \text{hr}} = 79\ \frac{\text{km}}{\text{hr}}$$

3. How far can you walk in 4.25 hours if you keep up a steady pace of 5.0000 km/hr? State your answer in km.

$$t = 4.25\ \text{hr}$$

$$v = 5.0000\ \frac{\text{km}}{\text{hr}}$$

$$d = ?$$

$$d = vt$$

$$d = 5.0000\ \frac{\text{km}}{\text{hr}} \cdot 4.25\ \text{hr} = 21.3\ \text{km}$$

4. For the previous problem, how far is this in miles?

$$21.3\ \text{km} \cdot \frac{1000\ \text{m}}{1\ \text{km}} \cdot \frac{1\ \text{ft}}{0.3048\ \text{m}} \cdot \frac{1\ \text{mi}}{5{,}280\ \text{ft}} = 13.2\ \text{mi}$$

5. On the German autobahn there is no speed limit and in good weather many cars travel at velocities exceeding 150.0 mi/hr. How fast is this in km/hr?

$$150.0\ \frac{\text{mi}}{\text{hr}} \cdot \frac{5{,}280\ \text{ft}}{1\ \text{mi}} \cdot \frac{0.3048\ \text{m}}{1\ \text{ft}} \cdot \frac{1\ \text{km}}{1000\ \text{m}} = 241.4\ \frac{\text{km}}{\text{hr}}$$

6. Referring again to the previous question, how long does it take a car at this velocity to travel 10.0 miles? State your answer in minutes.

$$v = 150.0\ \frac{\text{mi}}{\text{hr}} \cdot \frac{1\ \text{hr}}{60\ \text{min}} = 2.50\ \frac{\text{mi}}{\text{min}}$$

$$d = 10.0\ \text{mi}$$

$$t = ?$$

$$d = vt$$

$$t = \frac{d}{v}$$

$$t = \frac{10.0\ \text{mi}}{2.50\ \frac{\text{mi}}{\text{min}}} = 4.00\ \text{min}$$

7. An object travels 3.0 km at a constant velocity in 1 hr 20.0 min. Calculate the object's velocity and state your answer in m/s.

$$d = 3.0\ \text{km} \cdot \frac{1000\ \text{m}}{1\ \text{km}} = 3.0 \times 10^3\ \text{m}$$

$$t = 1\ \text{hr}\ 20.0\ \text{min} = 80.0\ \text{min} \cdot \frac{60\ \text{s}}{1\ \text{min}} = 4.80 \times 10^3\ \text{s}$$

$$v = ?$$

$$d = vt$$

$$v = \frac{d}{t} = \frac{3.0 \times 10^3\ \text{m}}{4.80 \times 10^3\ \text{s}} = 0.63\ \frac{\text{m}}{\text{s}}$$

8. A car starts from rest and accelerates to 45 mi/hr in 36 s. Calculate the car's acceleration and state your answer in m/s².

$$v_i = 0$$

$$v_f = 45\ \frac{\text{mi}}{\text{hr}} \cdot \frac{1\ \text{hr}}{60\ \text{min}} \cdot \frac{1\ \text{min}}{60\ \text{s}} \cdot \frac{5{,}280\ \text{ft}}{1\ \text{mi}} \cdot \frac{0.3048\ \text{m}}{1\ \text{ft}} = 20.1\ \frac{\text{m}}{\text{s}}$$

$$t = 36\ \text{s}$$

$$a = ?$$

$$a = \frac{v_f - v_i}{t} = \frac{20.1\frac{\text{m}}{\text{s}} - 0}{36\ \text{s}} = 0.56\ \frac{\text{m}}{\text{s}^2}$$

9. A rocket traveling at 31 m/s fires its retro-rockets, generating a negative acceleration (it is slowing down). The rockets are fired for 17 s and afterwards the rocket is traveling at 22 m/s. What is the rocket's acceleration?

$$v_i = 31\ \frac{\text{m}}{\text{s}}$$

$$t = 17\ \text{s}$$

$$v_f = 22\ \frac{\text{m}}{\text{s}}$$

$$a = ?$$

$$a = \frac{v_f - v_i}{t} = \frac{22\ \frac{\text{m}}{\text{s}} - 31\ \frac{\text{m}}{\text{s}}}{17\ \text{s}} = -0.53\ \frac{\text{m}}{\text{s}^2}$$

10. A person is sitting in a car watching a traffic light. The light is 14.5 m away. When the light changes color, how long does it take the new color of light to travel to the driver so that he can see it? State your answer in nanoseconds. (The speed of light in a vacuum or air, *c*, is one of the physical constants listed in Appendix A that you need to know.)

$$d = 14.5\ \text{m}$$

$$v = c = 3.00 \times 10^8\ \frac{\text{m}}{\text{s}}$$

$$t = ?$$

$$d = vt$$

$$t = \frac{d}{v} = \frac{14.5\ \text{m}}{3.00 \times 10^8\ \frac{\text{m}}{\text{s}}} = 4.83 \times 10^{-8}\ \text{s} \cdot \frac{10^9\ \text{ns}}{\text{s}} 48.3\ \text{ns}$$

11. A proton is uniformly accelerated from rest to 80.0% of the speed of light in 18 hours, 6 minutes, 45 seconds. What is the acceleration of the proton?

$$v_i = 0$$

$$v_f = 0.80 \cdot 3.00 \times 10^8\ \frac{\text{m}}{\text{s}} = 2.40 \times 10^8\ \frac{\text{m}}{\text{s}}$$

$$t = 18\ \text{hr}\ 6\ \text{min}\ 45\ \text{s} = 64800\ \text{s} + 360\ \text{s} + 45\ \text{s} = 65{,}205\ \text{s}$$

$$a = ?$$

$$a = \frac{v_f - v_i}{t} = \frac{2.40 \times 10^8\ \frac{\text{m}}{\text{s}} - 0}{65{,}205\ \text{s}} = 3{,}680\ \frac{\text{m}}{\text{s}^2}$$

12. A space ship travels 8.96 × 10⁹ km at 3.45 × 10⁵ m/s. How long does this trip take? Convert your answer from seconds to days.

$$d = 8.96\times10^{9}\ \text{km}\cdot\frac{1000\ \text{m}}{1\ \text{km}} = 8.96\times10^{12}\ \text{m}$$

$$v = 3.45\times10^{5}\ \frac{\text{m}}{\text{s}}$$

$$t = ?$$

$$d = vt$$

$$t = \frac{d}{v} = \frac{8.96\times10^{12}\ \text{m}}{3.45\times10^{5}\ \frac{\text{m}}{\text{s}}} = 2.597\times10^{7}\ \text{s}\cdot\frac{1\ \text{min}}{60\ \text{s}}\cdot\frac{1\ \text{hr}}{60\ \text{min}}\cdot\frac{1\ \text{day}}{24\ \text{hr}} = 301\ \text{days}$$

13. An electron experiences an acceleration of 5.556 × 10⁶ cm/s² for a period of 45 ms. If the electron is initially at rest, what is its final velocity?

$$a = 5.556\times10^{6}\ \frac{\text{cm}}{\text{s}^2}\cdot\frac{1\ \text{m}}{100\ \text{cm}} = 5.556\times10^{4}\ \frac{\text{m}}{\text{s}^2}$$

$$t = 45\ \text{ms}\cdot\frac{1\ \text{s}}{1000\ \text{ms}} = 4.5\times10^{-2}\ \text{s}$$

$$v_i = 0$$

$$v_f = ?$$

$$a = \frac{v_f - v_i}{t}$$

$$v_f = at + v_i = \left(5.556\times10^{4}\ \frac{\text{m}}{\text{s}^2}\right)\left(4.5\times10^{-2}\ \text{s}\right) + \left(0\ \frac{\text{m}}{\text{s}}\right) = 2.5\times10^{3}\ \frac{\text{m}}{\text{s}}$$

14. A space ship is traveling at a velocity of 4.005 × 10³ m/s when it switches on its rockets. The rockets accelerate the ship at 23.1 m/s² for a period of 13.5 s. What is the final velocity of the rocket?

$$v_i = 4.005\times10^{3}\ \frac{\text{m}}{\text{s}}$$

$$a = 23.1\ \frac{\text{m}}{\text{s}^2}$$

$$t = 13.5\ \text{s}$$

$$v_f = ?$$

$$a = \frac{v_f - v_i}{t}$$

$$v_f = at + v_i = \left(23.1\ \frac{\text{m}}{\text{s}^2}\cdot 13.5\ \text{s}\right) + 4.005\times10^{3}\ \frac{\text{m}}{\text{s}} = 4.32\times10^{3}\ \frac{\text{m}}{\text{s}}$$

15. A more precise value for *c* (the speed of light) than the value given in Appendix A is 2.9979 × 10⁸ m/s. Use this value for this problem. On a particular day the earth is 1.4965 × 10⁸ km from the sun. If on this day a solar flare suddenly occurs on the sun, how long does it take an observer on the earth to see it? State your answer in minutes.

$$v = c = 2.9979 \times 10^{8}\ \frac{\text{m}}{\text{s}}$$

$$d = 1.4965 \times 10^{8}\ \text{km} \cdot \frac{1000\ \text{m}}{1\ \text{km}} = 1.4965 \times 10^{11}\ \text{m}$$

$$t = ?$$

$$d = vt$$

$$t = \frac{d}{v} = \frac{1.4965 \times 10^{11}\ \text{m}}{2.9979 \times 10^{8}\ \frac{\text{m}}{\text{s}}} = 499.18\ \text{s} \cdot \frac{1\ \text{min}}{60\ \text{s}} = 8.3197\ \text{min}$$

Ptolemaic Model and Copernican Revolution Study Questions

1. Make a list of all the regions in the Ptolemaic Model in their correct order. (There are 10 of them, and the first nine are called spheres.) For each of the last three regions write a brief description of the meaning of the name.

Sphere 1 – Moon

Sphere 2 – Mercury

Sphere 3 – Venus

Sphere 4 – Sun

Sphere 5 – Mars

Sphere 6 – Jupiter

Sphere 7 – Saturn

Sphere 8 – The Firmament. This region consists of the stars arranged in their constellations according to the zodiac.

Sphere 9 – *The Primum Mobile*. This Latin name means "first mover." This sphere rotates around the earth every 24 hours and drags all the other spheres with it, making them all move.

Beyond – The Empyrean. This is the region beyond the spheres. The Empyrean is the abode of God, or the gods.

2. Describe why some theologians in the 16th century were strongly opposed to Copernicus' heliocentric theory.

Many theologians at the time did not understand that Scripture must be interpreted. Thus, they assumed that statements such as "He set the earth on its foundations so that it should never be moved" (Ps 104) and "The sun rises and the sun goes down, and hastens to the place where it rises" (Eccl 1) were literal descriptions of nature. In Copernicus' model, the earth orbits the sun, not vice versa, and this seemed to these theologians to be in direct contradiction to what Scripture taught.

3. State six features of the Ptolemaic model other than the spheres.

1. All seven of the heavenly bodies are perfectly spherical.
2. All heavenly bodies move in circular orbital regions, called spheres.
3. All the spheres are centered on the earth, so this system is a geocentric system.
4. Corruption and change only exist on earth. All other places in the universe are perfect and unchanging.
5. All the spheres containing the heavenly bodies and all the stars rotate completely around the earth every 24 hours.
6. Epicycles are used to explain retrograde motion.

4. Describe Copernicus' model of the heavens.

Copernicus proposed a detailed heliocentric model, with the earth rotating on an axis, all the planets moving in circular orbits around the sun, and the moon orbiting the earth. Copernicus' model used circular orbits, and like the Ptolemaic model, used epicycles to make the model work. Still, Copernicus' model was much closer to today's understanding than the Ptolemaic model was.

5. What are some of the "proofs" people used to argue that there was no way that the earth was rotating on an axis?

If you are simply observing from earth, it appears that everything is orbiting around the earth while the earth sits still. The sun and moon appear to rise each day, track across the sky, and set.

It also doesn't feel at all like the earth is rotating. Eratosthenes had already accurately estimated the circumference of the earth, so most scientists felt that if something that big were spinning in a circle once a day the people on its surface would be moving very fast. People on earth would have to hang on for dear life to keep from falling off. People used these arguments up until the time of Galileo to prove that there was no way the earth was orbiting the sun and spinning around once a day.

6. For what reason did Copernicus decide to keep his theory private?

Copernicus knew how committed the church theologians were to the Ptolemaic system and did not want to offend them with his ideas. He also did not want to be "hooted off the stage," as he wrote in *On the Revolutions of the Heavenly Spheres*. So he published his work privately to his close friends in 1514, and it became public at his death in 1543 when one of Copernicus' admirers got it published.

7. Write a description of the two key observations Tycho made (including dates) that challenged the Ptolemaic system.

First, in 1563 he observed a conjunction between Jupiter and Saturn. A conjunction is when two planets are in a straight line with the earth, so that from earth they appear to be in the same place in the sky. Tycho closely predicted the date for this conjunction using Copernicus' new heliocentric model. Second, in 1572 he observed what he called a "nova" (what we would now call a supernova) and proved that it was a new star. This discovery was strong evidence that the stars were not perfect and unchanging as Aristotle had thought and as Church doctrine declared.

8. Briefly describe the cosmological model put forward by Tycho.

In Tycho's model, the sun and moon orbit the earth. All the other planets orbit the sun, which orbits the earth. Tycho was able to avoid controversy since in his model the sun and moon orbit the earth and the earth is stationary, which lines up with a literal reading of the Bible.

9. State Kepler's first law of planetary motion.

Each of the planetary orbits is an ellipse, with the sun at one focus.

10. This is a bit difficult, but explain retrograde motion and epicycles as well as you can in a few sentences.

The planets all appear to move against the starry background night after night. Retrograde motion is the appearance to observers on earth of a planet "backing up" in its motion relative to the stars. An epicycle is a circular path around a center point, and the center point itself travels on a circular path around something else. The motion of a planet moving an epicycle is like that of a person in the "tea cup" ride at an amusement park.

11. Explain the two main mistakes individuals made that led to Galileo's trial.

The theologians made the mistake of assuming that Scripture could be read literally without interpretation. Galileo made the mistake of insisting that his mathematical models were true and that nature needed no interpretation.

12. Explain the actual cause of Galileo's trial and the results of that trial.

Galileo was tried for violating an injunction not to teach, hold, or defend Copernicus' system as true. Galileo realized that he had violated this order, and he repented. He lived the final nine years of his life under house arrest as a result of the trial.

13. Describe why Pope John Paul II commended Galileo in 1992.

Galileo was commended for his recognition that the Scriptures do, in fact, require interpretation.