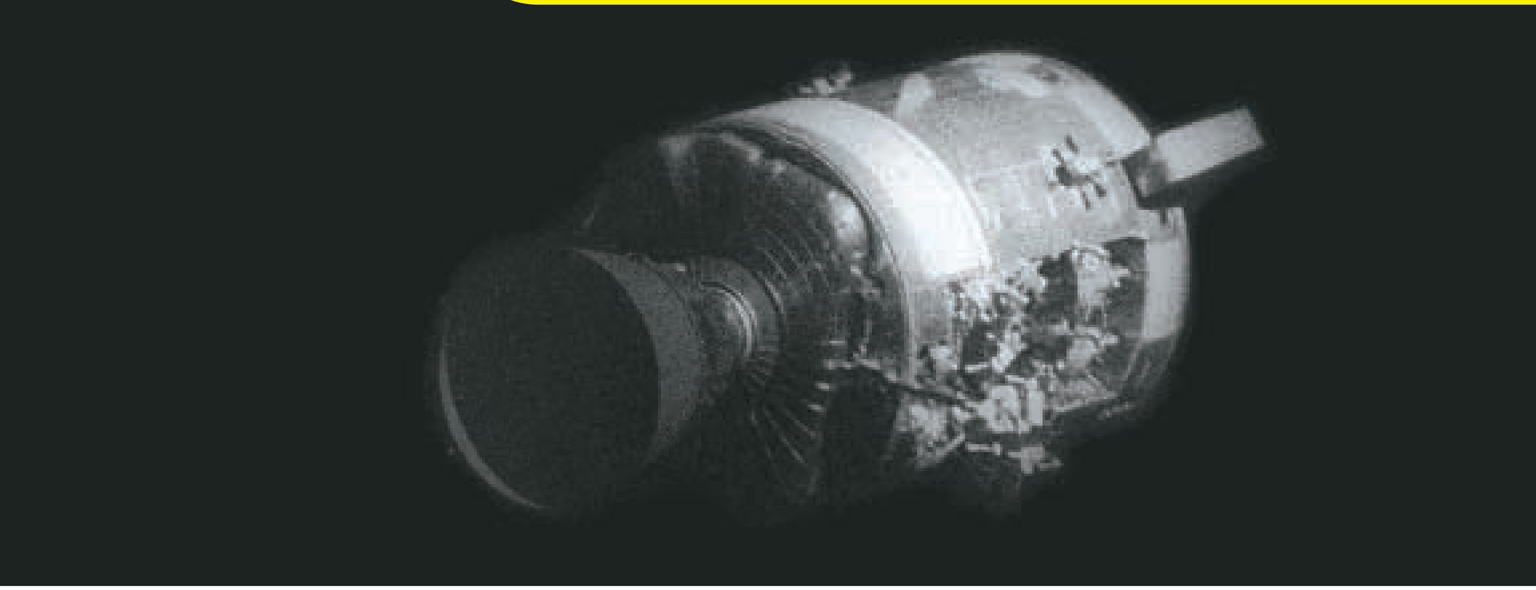
CHAPTER 12 Universal Gravitation



CHAPTER CONTENTS

On April 13, 1970, almost 56 h and 333 000 km into their flight to the Moon, the crew of *Apollo 13* heard a loud bang and felt the spacecraft shudder. Astronaut Jack Swigert radioed NASA Ground Control: "Houston, we've had a problem here." The above photograph, taken by the astronauts after they jettisoned the service module, shows how serious that problem was — an oxygen tank had exploded and damaged the only other oxygen tank. After assessing the situation, the astronauts climbed into the lunar landing module, where the oxygen and supplies were designed to support two people for two days. They would have to support the three astronauts for four days.

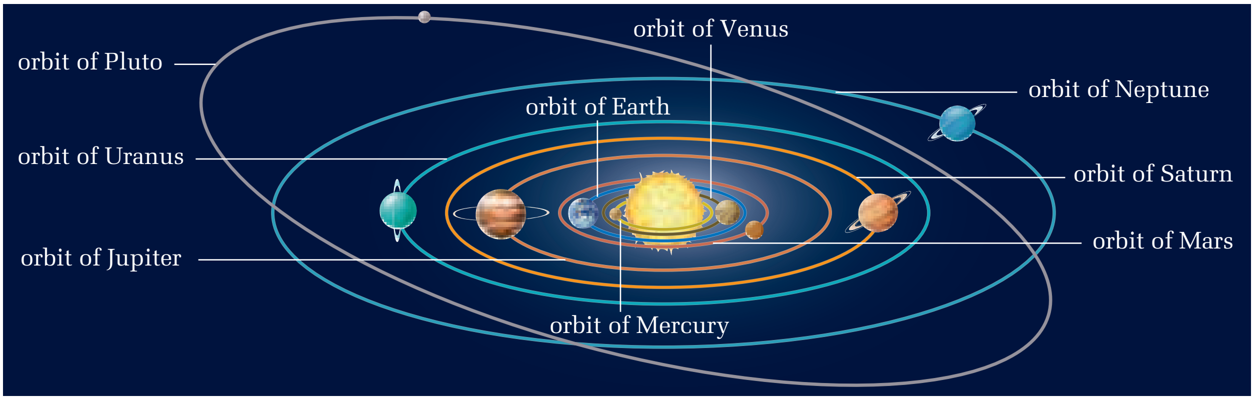
The spacecraft was still hurtling toward the Moon at more than 5000 km/h, and the engines of the lunar landing module could certainly not provide the force necessary to turn the craft back toward Earth. The only available force that could send the astronauts home was the gravitational force of the Moon, which swung the crippled spacecraft around behind the Moon and hurled it back toward Earth. With the engines of the lunar landing module, the crew made two small course corrections that prevented the craft from careening past Earth into deep space. Exactly 5 days, 22 h, and 54 min after lift-off, the astronauts, back inside the command module, landed in the Pacific Ocean, less than 800 m from the rescue ship.

In this chapter, you will learn about Newton's law of universal gravitation and how it guides the motion of planets and satellites — and damaged spacecraft.

QUICK LAB

Kepler's Empirical Equations

TARGET SKILLS
- Initiating and planning
- Analyzing and interpreting
- Communicating results



The famous German astronomer Johannes Kepler (1571–1630) studied a vast amount of detailed astronomical data and found three empirical mathematical relationships within these data. Empirical equations are based solely on data and have no theoretical foundation. Often, however, an empirical equation will provide scientists with insights that will lead to a hypothesis that can be tested further.

In this chapter, you will learn the significance of Kepler's empirical equations. First, however, you will examine the data below, which is similar to the data that Kepler used, and look for a relationship.

Planet	Orbital radius *R* (AU)*	Orbital period *T* (days)
Mercury	0.389	87.77
Venus	0.724	224.70
Earth	1.000	365.25
Mars	1.524	686.98
Jupiter	5.200	4332.62
Saturn	9.150	10 759.20

* One astronomical unit (AU) is the average distance from Earth to the Sun, so distances expressed in AU are fractions or multiples of the Earth's average orbital radius.

From the data, make a graph of radius (R) versus period (T). Study the graph. Does the curve look like an inverse relationship, a logarithmic relationship, or an exponential relationship? Choose the type of mathematical relationship that you think is the most likely. Review Skill Set 4, Mathematical Modelling and Curve Straightening, and make at least four attempts to manipulate the data and plot the results. If you found a relationship that gives you a straight-line plot, write the mathematical relationship between radius and period. If you did not find the correct relationship, confer with your classmates to see if anyone found the correct relationship. As a class, agree on the final mathematical relationship.

Analyze and Conclude

1. When Kepler worked with astronomical data, he did not know whether a relationship existed between specific pairs of variables. In addition, Kepler had no calculator — he had to do all of his calculations by hand. Comment on the effort that he exerted in order to find his relationships.
2. Think about the relationship between the radius of an orbit and the period of an orbit on which your class agreed. Try to think of a theoretical basis for this relationship.
3. What type of additional information do you think that you would need in order to give a physical meaning to your mathematical relationship?