Physics 20 Lesson 22 Gravitational Field Strength

Refer to Pearson pages 216 to 229 for a discussion of gravitational field strength.

I. Gravitational field strength (acceleration due to gravity)

Near the surface of the Earth all objects, regardless of size or shape, are subject to an average acceleration due to gravity of 9.81 m/s^2 acting downward toward the center of the Earth. Another name for this acceleration is ***gravitational field strength***. As you move away from the center of the Earth, the gravitational field strength decreases in magnitude, but its direction remains unchanged. The gravitational field strength is different for different planets and moons.

When we calculate the gravitational **force** of attraction between an object and the Earth, we could use the *Universal Law of Gravitation* equation

$$F_g = G\frac{m_1 m_2}{r^2}$$

or we could use the more familiar

$$F_g = mg = ma_g$$

When we make these equations equal to one another, we get:

$$F_g = F_g$$

$$ma_g = G\frac{m_1 m_2}{r^2} \quad \text{(recognizing that } m = m_2\text{)}$$

$$m_2 a_g = G\frac{m_1 m_2}{r^2} \quad \text{(} m_2 \text{ cancels)}$$

$$a_g = G\frac{m_1}{r^2} \quad \text{(where r is the radius and } m_1 \text{ is the mass of the planet)}$$

The gravitational field strength or the acceleration due to gravity for a planet or moon is calculated using this formula.

Example 1

What is the gravitational field strength on the surface of Neptune?

From the table at the end of this lesson we find the mass and radius of Neptune.

$$a_g = G\frac{m_1}{r^2}$$

$$a_g = 6.67\times10^{-11}\,\tfrac{Nm^2}{kg^2}\frac{(1.03\times10^{26}kg)}{(2.48\times10^{7}m)^2}$$

a_g = **11.17 N/kg** or **11.17 m/s²**

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Example 2

What is the gravitational field strength at a distance of 1.914 x 10^7 m above the surface of the Earth? If a person weighs 400 N on the surface, what would he weigh at this distance?

From the data table on the formula sheet we find the mass and radius of Earth.

r = r_E + altitude = 6.37 x 10^6 m + 1.914 x 10^7 m = 2.551 x 10^7 m

$$a_g = G\frac{m_1}{r^2}$$

$$a_g = 6.67\times10^{-11}\,\tfrac{Nm^2}{kg^2}\,\frac{(5.98\times10^{24}\,kg)}{(2.551\times10^{7}\,m)^2}$$

a_g = **0.613 N/kg**

The person's mass can be calculated using $F_g = m\,a_g$ (a_g = 9.81 N/kg on the surface)

$$m = \frac{F_g}{a_g}$$

$$m = \frac{400N}{9.81\frac{N}{kg}}$$ m = F_g/g = 400 N/(9.81 m/s^2) = 40.77 kg

$$m = 40.77\,kg$$

The person's new weight can be calculated using:

$$F_g = ma_g$$

$$F_g = 40.77\,kg(0.613\,\tfrac{N}{kg})$$

F_g = **25 N** at 1.914 x 10^7 m above the Earth

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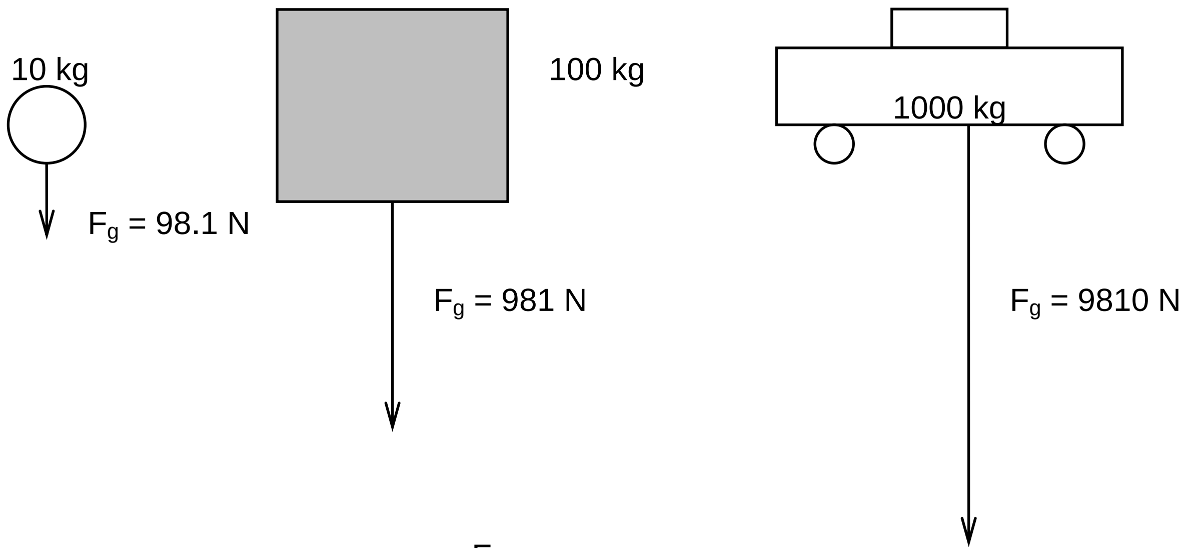
II. Gravitational force ≠ gravitational field strength

Some confusion may exist between the concepts of *gravitational field strength* and *gravitational force*. Consider three objects like those depicted below. Each object experiences the <u>same</u> gravitational field strength of $-9.81\ m/s^2$, assuming that we are on Earth, but each object experiences a <u>different</u> force since each object has a different mass.



$$F_g = m\,g$$

III. Practice problems

1. What is the gravitational field strength on the surface of Earth? What is the gravitational field strength 100 km above the surface of Earth? ($9.81\ m/s^2$, $9.53\ m/s^2$)

2. You are on a planet whose radius is known to be about 4500 km. You then perform the following experiment: You drop a rock from a height of 10.0 m and measure the time of its fall to be 2.65 s. What is the mass of the planet? (8.65×10^{23} kg)

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IV. Hand-in assignment

Use the data table below to help you do the following problems.

The Solar System

Object	**Mass (kg)**	**Radius of object (m)**	**Period of rotation on axis (s)**	**Mean radius of orbit (m)**	**Period of revolution of orbit (s)**
Sun	1.98×10^{30}	6.95×10^{8}	2.14×10^{6}	–	–
Mercury	3.28×10^{23}	2.57×10^{6}	5.05×10^{6}	5.79×10^{10}	7.60×10^{6}
Venus	4.83×10^{24}	6.31×10^{6}	2.1×10^{7}	1.08×10^{11}	1.94×10^{7}
Earth	5.98×10^{24}	6.37×10^{6}	8.61×10^{4}	1.49×10^{11}	3.16×10^{7}
Mars	6.37×10^{23}	3.43×10^{6}	8.85×10^{4}	2.28×10^{11}	5.91×10^{7}
Jupiter	1.90×10^{27}	7.18×10^{7}	3.54×10^{4}	7.78×10^{11}	1.74×10^{8}
Saturn	5.67×10^{26}	6.03×10^{7}	3.60×10^{4}	1.43×10^{12}	9.30×10^{8}
Uranus	8.80×10^{25}	2.67×10^{7}	3.88×10^{4}	2.87×10^{12}	2.66×10^{9}
Neptune	1.03×10^{26}	2.48×10^{7}	5.69×10^{6}	4.50×10^{12}	5.20×10^{9}
Pluto	6×10^{23}	3×10^{6}	5.51×10^{5}	5.9×10^{12}	7.82×10^{9}
Moon	7.34×10^{22}	1.74×10^{6}	2.36×10^{6}	3.8×10^{8}	2.36×10^{6}

1. Calculate the acceleration due to gravity on Jupiter. (24 m/s^2)

2. If a man weighs 780 N on Earth, what would he weigh on the moon? (129 N)

3. The instrument payload of a rocket weighs 890 N on Earth. What does it weigh at an altitude of 25520 km above the surface of the Earth? (35.3 N)

4. Calculate the acceleration due to gravity on Saturn. How much will a 60 kg man weigh on the surface of Saturn? (10.4 m/s^2, 624 N)

5. At the top of Mt. Robson in British Columbia, a 7.50 kg turkey weighs 72.6 N. Calculate the magnitude of the gravitational field strength at this location. (9.68 N/kg)

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V. Activity

Read Pearson pages 226 to 228 and then do **QuickLab 4-4**.

Problem

What is the motion of water in a cup when the cup is dropped from several metres above Earth's surface?

Materials

paper cup
pointed pen or pencil
water
food coloring
stepladder
thinking students

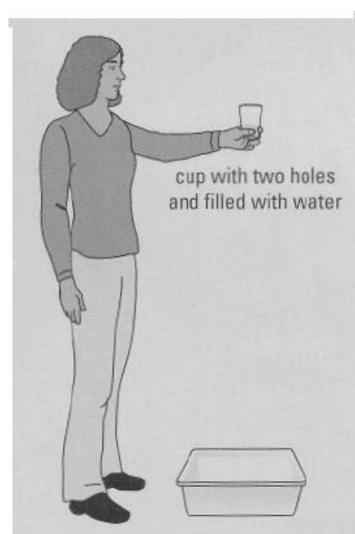
Procedure

CAUTION: Do this activity outside. Have someone steady the ladder and be careful when climbing it.

1. Ask your kind and benevolent instructor for the materials for the activity.

2. Make two small holes on opposite sides of the cup near the bottom using the pen or pencil. Cover the holes with your thumb and forefinger. Then fill the cup with colour water.

3. Hold the cup at shoulder height above the ground and uncover the holes. Observe what happens to the water. Have a partner sketch the path the water takes.



4. Read step 5 but before proceeding with step 5, **predict** what will happen when you drop the cup. **Explain your prediction**.

5. Refill the cup, climb the ladder and drop the cup from a height of several metres. Observe the motion of the water during the fall.

Questions

1. Describe the path and motion of the water
   (a) when the cup was held stationary, and
   (b) when the cup was dropped from the ladder. Give a reason for your observations. How do you observations compare with your predictions? Explain.