

chapter 7 supplemental problems gravitation answer key

Published: September 27, 2026 | Index ID: #-

Chapter 7 Supplemental Problems: Gravitation Answer Key

Gravity is the invisible force that binds the universe together. From the motion of planets around the Sun to the fall of an apple from a tree, the laws of gravitation govern everything. In physics textbooks, Chapter 7 is usually devoted to Newton's law of universal gravitation and its many applications. Supplemental problems are designed to test a student's grasp of the concepts, sharpen problem solving skills, and reinforce the mathematical techniques required to tackle real world scenarios.

Finding a reliable answer key is often the first hurdle for students. A well structured key not only gives the final answer but also explains the reasoning behind each step, allowing learners to understand the logic and avoid common pitfalls. This article provides a comprehensive, step by step answer key for the most common types of problems found in Chapter 7 supplemental worksheets. It is written in clear, human friendly language while maintaining the rigor expected of high school and introductory college physics courses.

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1. Newton's Law of Universal Gravitation

Newton's law states that every point mass attracts every other point mass with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between them:

$$F = G \frac{(m_1 \cdot m_2)}{r^2}$$

where G is the universal gravitational constant, m_1 and m_2 are the masses, and r is the separation. Problems in this section often ask students to calculate the force between two bodies, determine the mass of an object given a force, or solve for the distance between two masses.

Common Mistakes to Avoid

- Confusing r with the radius of a sphere instead of the center to center distance.
- Using inconsistent units (e.g., mixing kilograms with grams).
- Neglecting the direction of the force (always attractive).

2. Gravitational Potential Energy

The gravitational potential energy (U) of a mass m at a distance r from a mass M is given by:

$$U = -G M m / r$$

Negative sign indicates that the energy is lower (more bound) when the masses are closer. Typical problems involve calculating the potential energy of a satellite, the energy change during a free fall, or the work required to lift an object against gravity.

Key Formulae

1. Change in potential energy: $\Delta U = -\int F dr$
2. Total mechanical energy: $E = K + U$, where K is kinetic energy.
3. For circular orbits: $E = -\frac{1}{2} G M m / r$.

3. Escape Velocity

Escape velocity is the minimum speed required for an object to break free from a planet's gravitational pull without further propulsion. It is derived from setting kinetic energy equal to the absolute value of gravitational potential energy:

$$v = \sqrt{2 G M / R}$$

where M is the planet's mass and R is its radius. Problems often require calculating the escape velocity from Earth, the Moon, or other celestial bodies, or determining the mass of a planet given its escape velocity.

4. Orbital Mechanics

Orbital motion is governed by Newton's laws and Kepler's laws. For circular orbits, the orbital speed (v) is:

$$v = \sqrt{G M / r}$$

For elliptical orbits, the vis viva equation generalizes this relationship:

$$v^2 = G M (2/r - 1/a)$$

where a is the semi major axis. Problems in this section include calculating orbital periods, velocities at periaapsis and apoapsis, and the energy of orbiting bodies.

Kepler's Third Law (Simplified)

$T^2 \propto a^3$ for orbits around the same central mass.

5. Gravitational Fields and Forces

The gravitational field g at a distance r from a mass M is defined as the force per unit mass:

$$g = G M / r^2$$

Problems often ask students to compute the field at various points, determine the force on a mass in a non uniform field, or analyze superposition of fields from multiple masses.

6. Tidal Forces and Earth Moon Interaction

Tidal forces arise from the differential gravitational pull across an extended body. The tidal acceleration a between two points separated by distance d at a distance r from the attracting mass is approximately:

$$a \propto \frac{2 G M d}{r^3}$$

Problems may involve estimating the tidal bulge on Earth due to the Moon, calculating the tidal torque, or explaining the synchronization of Earth's rotation with the Moon's orbit.

7. Sample Problems and Detailed Solutions

Below is a curated selection of typical supplemental problems from Chapter 7, along with thorough solutions. Each problem is followed by a step by step explanation, ensuring that readers can grasp the underlying physics and mathematical techniques.

Problem 1: Force Between Two Masses

A 2 kg mass and a 3 kg mass are separated by 0.5 m. Calculate the gravitational force between them.

1. Identify the given values:

$$m_1 = 2 \text{ kg}$$

$$m_2 = 3 \text{ kg}$$

$$r = 0.5 \text{ m}$$

$$G = 6.674 \times 10^{-11} \text{ N m}^2/\text{kg}^2$$

$$F = G \frac{m_1 m_2}{r^2} = 6.674 \times 10^{-11} \times \frac{(2 \times 3)}{(0.5)^2}$$

- Product of masses: 6 kg²
- r^2 : 0.25 m²
- Numerator: $6.674 \times 10^{-11} \times 6 = 4.0044 \times 10^{-10}$
- Divide by 0.25: $1.60176 \times 10^{-9} \text{ N}$

Problem 2: Gravitational Potential Energy of a Satellite

A 500 kg satellite orbits Earth at an altitude of 300 km. Compute its gravitational potential energy relative to Earth's surface.

1. Convert altitude to radius:

$$\text{Earth's radius, } R = 6.371 \times 10^6 \text{ m}$$

$$\text{Orbit radius, } r = R + 300,000 \text{ m} = 6.671 \times 10^6 \text{ m}$$

- $M = 5.972 \times 10^{24} \text{ kg}$
- $m = 500 \text{ kg}$
- $G = 6.674 \times 10^{-11}$
- $G \frac{M}{r} = 6.674 \times 10^{-11} \times \frac{5.972 \times 10^{24}}{6.671 \times 10^6} = 1.993 \times 10^7 \text{ J/m}$
- $U = -1.993 \times 10^7 \times \frac{500}{6.671 \times 10^6} = -1.497 \times 10^{11} \text{ J}$

Problem 3: Escape Velocity from Mars

Calculate the escape velocity from the surface of Mars (mass = $6.417 \times 10^{23} \text{ kg}$, radius = $3.389 \times 10^6 \text{ m}$).

1. Apply $v = \sqrt{2GM/R}$:

$$2GM/R = 2 \times 6.674 \times 10^{-11} \times \frac{6.417 \times 10^{23}}{3.389 \times 10^6} = 8.568 \times 10^{13}$$

$$\text{Divide by } R: 8.568 \times 10^{13} // 3.389 \times 10^6 = 2.529 \times 10^7$$

$$\text{Square root: } \sqrt{2.529 \times 10^7} = 5.03 \times 10^3 \text{ m/s}$$

Problem 4: Orbital Period of a Low Earth Satellite

A satellite is in a circular orbit at an altitude of 400 /km. Find its orbital period.

1. Compute orbital radius: $r = R_{\oplus} + 400\,000 = 6.771 \times 10^6 \text{ m}$.
2. Orbital speed: $v = \sqrt{GM_{\oplus}/r} = 7.67 \times 10^3 \text{ m/s}$.

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