Grade 6 Physics — 45-minute Quiz: Gravity and Orbits

Total time: 45 minutes. Total marks: 75. Read each question carefully. Show complete reasoning: state axioms or principles you begin with, list each inference as a numbered logical step, provide an evidence log entry for any factual claim or number you use, and label your final answer. Use $g = 9.8\ m/s^2$ and Earth radius $R = 6.37 \times 10^6$ m when needed. Calculators allowed.

Special Education Accommodations and Scaffolds (use as needed)

- Extended time: +50% time.
- Read-aloud: examiner reads questions verbatim.
- Simplified language version available (ask proctor).
- Sentence starters and logic-template:
  - Axiom/principle: “I start from: …”
  - Inference 1: “From this I infer: … because …”
  - Evidence log line: “Source/Datum: … supports claim …”
  - Conclusion: “Therefore: …”

- Graphic organizer (evidence-mapping table) provided on exam paper back page:
  - Claim | Warrant (why claim follows) | Backing (data/source) | Level of confidence

- Calculator allowed; provide scratch paper. Visual aids: simple diagrams allowed for explanation.

Scoring notes (apply for each question)

- Each question requires: (a) statement of starting axiom/principle, (b) numbered inference steps with brief justification, (c) evidence log(s) citing the source or data used, (d) labeled final answer.
- Partial credit awarded for correct reasoning steps even if final numeric value is off due to arithmetic.

Questions

Questions 1–5: 4 marks each (total 20)

1. (4 marks) State a fundamental axiom about gravity that you will use for the rest of the quiz.

Then, using that axiom, give two distinct logical inferences about why an apple falls to the ground when released. Number each inference and include an evidence log entry for each inference.
Scoring: 2 marks for correct axiom; 1 mark each for each inference with justification and evidence.

2. (4 marks) Define mass and weight. Starting from the axiom “weight is the force due to gravity on an object,” derive the relation $W = m\cdot g$ in three numbered logical steps. Use the relation to compute the weight (N) of a 10.0 kg object and include an evidence log that cites the numerical value used for g.
Scoring: 1 mark definition of mass; 1 mark definition of weight; 1 mark correct derivation steps; 1 mark correct numeric answer with evidence.

3. (4 marks) Begin with the principle “near Earth’s surface acceleration due to gravity is constant (g).” Show, in numbered logical steps, why an object released from rest has velocity $v = g\cdot t$ after t seconds. Then compute v after 3.0 s. Provide an evidence log entry for the equation used.
Scoring: 2 marks derivation steps; 1 mark numeric computation; 1 mark evidence log.

4. (4 marks) Using the same starting principle as Q3, derive (without calculus) the distance formula s = 1/2 g t^2 for an object dropped from rest. Use the “average velocity = (initial + final)/2” argument in numbered steps. Compute distance fallen in 3.0 s. Cite evidence for each formula used.
Scoring: 2 marks derivation; 1 mark numeric result; 1 mark evidence log.

5. (4 marks) A student claims: “Gravity stays the same no matter how far you are from Earth.” Analyze this claim. List the implicit assumptions in that claim, produce a counterexample (qualitative or numeric) that shows the claim can be false, and state a corrected claim. Map your reasoning in numbered steps and include an evidence log entry that supports the corrected claim.
Scoring: 1 mark for listing assumptions; 1.5 marks for a correct counterexample with reasoning; 1.5 marks for corrected claim and evidence.

Questions 6–10: 5 marks each (total 25)

6. (5 marks) Explain why a satellite in low Earth orbit (LEO) does not fall straight to Earth. Begin with the axiom “gravity provides a central acceleration toward Earth” and use a chain of reasoning to show how horizontal speed and gravity combine to make orbit. Include an evidence log that cites the qualitative mechanism (“falling around” concept) and label your conclusion.
Scoring: 2 marks for logical chain showing interplay of horizontal speed and gravity; 2 marks for correct conclusion; 1 mark evidence log.

7. (5 marks) Use the simplified circular-orbit relation a_c = v^2 / r and the near-surface value g to derive v = sqrt(g·r) as an estimate for circular orbital speed at radius r (show each algebraic step). Then compute v for r = R (near-Earth surface) using $g = 9.8\ \text{m/s}^2$ and R = 6.37 × 10^6 m. Include an evidence log for the formulas used.

Scoring: 2 marks derivation with algebra steps; 2 marks numeric calculation (to three significant figures); 1 mark evidence log.

8. (5 marks) Tides on Earth are affected by the Moon's gravity. Starting from the axiom "gravity depends on mass and distance," create a numbered chain of reasoning that explains how the Moon causes two tidal bulges on opposite sides of Earth. Identify at least one simplifying assumption in your chain and perform a brief bias/audit noting the limitation this assumption introduces. Provide evidence/log items that support each major step.
   Scoring: 3 marks for correct chain explaining two bulges; 1 mark for identifying assumption and bias audit; 1 mark evidence log.

9. (5 marks) A peer writes: "Heavier satellites must orbit faster because heavier objects fall faster." Critique this reasoning in numbered logical steps, identify the central error, propose the corrected scientific statement, and support your correction with an evidence mapping: claim | warrant | backing.
   Scoring: 2 marks for critique and identification of error; 2 marks for corrected statement with justification; 1 mark for clear evidence mapping.

10. (5 marks) Create an evidence-mapping table (Claim / Warrant / Backing / Confidence) for the claim: "A satellite at 500 km altitude will remain in orbit for at least one year without propulsion." List at least three warrants/backing items you would need to support this claim (e.g., atmosphere density, satellite cross-section, initial speed). For each backing item, note its likely effect (increase/decrease) on orbital lifetime and assign a confidence level (high/medium/low) with justification.
    Scoring: 2 marks for a clear table with three correct backing items; 2 marks for correct effect analysis; 1 mark for justified confidence levels.

Questions 11–15: 6 marks each (total 30)

11. (6 marks) Multi-step derivation: Start from Newton's law of universal gravitation in words ("Every pair of masses attracts with a force that increases with mass and decreases with distance.") and from the centripetal acceleration requirement for circular motion (a_c = v^2 / r). Show, in numbered algebraic and logic steps, how these lead to v = sqrt(G·M / r) for a small mass m orbiting a large mass M. You do not need to compute G or plug numbers. Include evidence log entries for the laws used and label each algebraic substitution.
    Scoring: 2 marks correctly stating the laws; 3 marks for correct algebraic steps and substitutions; 1 mark evidence log.

12. (6 marks) Bias audit and corrected measurement: A class measures g by dropping a small ball from height 2.00 m and timing the drop. Their mean recorded time is 0.64 s. (a) Using s = 1/2 g t^2, compute g implied by this measurement. (b) List and explain three sources of bias or systematic error that could cause measured g to differ from true g. (c) If air resistance reduced acceleration by 0.20 m/s² for this ball, recompute expected fall time from 2.00 m using s = 1/2 a_eff t^2 where a_eff = g − 0.20. Provide evidence and justification for each step.
    Scoring: 2 marks for correct g calculation; 2 marks for listing and explaining three bias sources; 2 marks for recomputed time and justification.

13. (6 marks) Comparative critique: Two models for orbit decay are proposed.

- Model A: Orbit decay is caused only by atmospheric drag and thus only occurs below 1,000 km.
- Model B: Orbit decay can be caused by atmospheric drag, solar activity (expanding atmosphere), and gravitational perturbations; therefore decay can occur at many altitudes over time.
  In numbered steps, critique Model A, identify strengths and weaknesses of Model B, and defend which model better fits the evidence. Provide at least two pieces of real or plausible evidence (with sources or data statements in your evidence log) to support your defense.
  Scoring: 2 marks critique of Model A; 2 marks analysis of Model B; 2 marks defense with two pieces of evidence and evidence log.

14. (6 marks) Reflective success-check: Choose one numeric question you completed in this quiz (state which). For that question, write a two-part reflective response: (A) map each success criterion for that question (accuracy, justification, evidence) to the exact part of your solution that satisfies it (quote or line number), and (B) list the Depth of Knowledge (DOK) level(s) targeted by the question (recall, skill/concept, strategic thinking, extended reasoning) and explain why. Be explicit and concise.
    Scoring: 3 marks for clear mapping of success criteria to solution parts; 3 marks for accurate DOK identification and justification.

15. (6 marks) Open synthesis and recommendation: A space agency must decide between placing a new space telescope in Low Earth Orbit (LEO, ~~500 km altitude) or at the Sun–Earth L2 point (~~1.5 million km from Earth). The telescope requires stable pointing, minimal Earth blockage, and long mission lifetime with few service opportunities. Using chains of reasoning beginning from core axioms about gravity and orbits, evaluate both options. Produce:

- A ranked recommendation (LEO or L2) labeled as your choice.
- A numbered chain of evidence (at least three items) that justifies your recommendation, showing claims, warrants, and backing.
- A short bias audit (one paragraph) about what perspectives or data limitations could change your recommendation.
  Include an evidence log that cites at least two specific factors (e.g., atmospheric drag, distance to Earth, radiation environment) and state your confidence in the recommendation.
  Scoring: 3 marks for a correct, well-justified recommendation with chain of evidence; 2 marks for the evidence log and confidence statements; 1 mark for bias audit.

Evidence Log and Mapping Template (use for all items)

Provide at least one entry per question where evidence is required. Use format:

- Item #: Source/Data — What it supports — Confidence (H/M/L)
  Example: Q3: “Equation $v = g \cdot t$” — kinematic relation for constant acceleration — Confidence: H (standard physics relation).

Answer Key with Scoring Guidance and Explanations

General scoring guidance: award partial credit for correctly stated axioms, correct intermediate inference steps, correct algebra, correct evidence logs, and correct final answers. Each answer below includes expected reasoning steps and exemplar responses. Use these to assign points as indicated per question.

1. (4 marks) Exemplar answer:

- Axiom (2 marks): “Masses attract each other; near Earth’s surface this attraction produces an acceleration $g \approx 9.8\ \mathrm{m/s^2}$ downward.” (Full 2 marks)
- Inference 1 (1 mark): “If an apple is released (no upward forces), gravity produces downward acceleration -> apple speeds toward ground.” Evidence: observation of falling objects; citation: ‘classroom observation; standard kinematics’ (1 mark).
- Inference 2 (1 mark): “If two objects of different mass are dropped (neglecting air resistance), both accelerate at same rate g -> both hit ground at same time.” Evidence: historical experiment (Galileo); cite basic physics textbook or class demo. (1 mark)
  Scoring: award partial for weaker axiom wording; require both inferences justified.

2. (4 marks) Exemplar:

- Definitions (2 marks): Mass = amount of matter (kg). Weight = force due to gravity on mass (N). (1 mark each)
- Derivation (1 mark): Start: Weight is force by gravity -> $W = m \cdot a_{gravity}$; near Earth $a_{gravity} = g$ => $W = m \cdot g$. Numbered steps: 1) Weight is gravitational force on object; 2) Force = mass × acceleration; 3) acceleration = g -> $W = m \cdot g$.
- Numeric (1 mark): $W = 10.0\ \mathrm{kg} \times 9.8\ \mathrm{m/s^2} = 98\ \mathrm{N}$. Evidence log: “Used $g = 9.8\ \mathrm{m/s^2}$ (class constant).”
  Scoring: partial credit if units omitted or arithmetic minor.

3. (4 marks) Exemplar:

- Steps (2 marks): 1) Axiom: acceleration $a = g$ constant. 2) Starting from rest: initial velocity $u = 0$. By definition of acceleration, $a = (v - u)/t$ -> $v = u + a t$ -> $v = 0 + g t$ -> $v = g t$. Numbered steps shown.
- Numeric (1 mark): $v = 9.8 \times 3.0 = 29.4\ \mathrm{m/s}$. Evidence log: “Equation $v = u + at$ for constant acceleration (standard kinematic). Confidence H.”

- Award partial if student uses $g = 10$ resulting $v = 30$ m/s — accept with note and full evidence.
  Scoring: 2/2 for correct logic even if arithmetic off.

4. (4 marks) Exemplar:

- Derivation (2 marks): Using average velocity method: initial $u = 0$, final $v = g\,t$. Average velocity $= (u + v)/2 = (0 + g\,t)/2 = 1/2\,g\,t$. Distance $s =$ average velocity × time $= (1/2\,g\,t)\cdot t = 1/2\,g\,t^2$. Steps numbered.
- Numeric (1 mark): $s = 0.5 \times 9.8 \times 3.0^2 = 0.5 \times 9.8 \times 9 = 44.1$ m.
- Evidence log (1 mark): “Used $v = g\,t$ and average velocity relation from kinematics.”
  Scoring: partial credit for method shown even if arithmetic slightly off.

5. (4 marks) Exemplar:

- Assumptions (1 mark): Student’s claim assumes either (a) Earth’s mass/distance relationship has no effect, or (b) gravitational field strength is uniform at all distances.
- Counterexample (1.5 marks): “At 2× Earth radius (distance from Earth center), gravitational acceleration is weaker. Since $g \propto 1/r^2$, doubling r reduces g to 1/4; thus gravity is not same at different distances.” Evidence log: cite inverse-square relation concept or reason qualitatively that force weakens with distance.
- Corrected claim (1.5 marks): “Gravity from Earth decreases with increasing distance from Earth roughly following an inverse-square relation; near Earth’s surface variation is small but not zero.” Provide evidence: Newton’s law or observed satellite behavior.
  Scoring: accept qualitative inverse relation explanation; partial credit if student uses proportional reasoning without formula.

6. (5 marks) Exemplar:

- Chain (2 marks): 1) Axiom: gravity pulls satellite toward Earth center. 2) If satellite has horizontal velocity, as it falls due to gravity Earth’s surface curves away; thus continuous free-fall with forward motion results in orbit (“falling around”). 3) So orbit is balance between gravitational pull (providing centripetal acceleration) and tangential speed. Numbered steps.
- Conclusion (2 marks): “A satellite stays in orbit because its horizontal speed causes it to continuously fall around Earth without hitting it when centripetal requirement is met.” Label conclusion.
- Evidence log (1 mark): cite classical explanation of orbital motion (e.g., Newton’s cannonball thought experiment) or class resource.
  Scoring: award for clear chain; accept diagrams but require numbered logic.

7. (5 marks) Exemplar:

- Derivation (2 marks): Start with centripetal acceleration $a_c = v^2 / r$; set $a_c = g$ (for near-surface circular orbit approximation) $\rightarrow v^2 / r = g \rightarrow v^2 = g\,r \rightarrow v = \sqrt{g\,r}$.
- Numeric (2 marks): $v = \sqrt{9.8 \times 6.37\times10^6} = \sqrt{62{,}426{,}000} \approx 7{,}900$ m/s (more precisely $\sim 7.93 \times 10^3$ m/s). Show arithmetic; award 2 marks for correct value to three significant

figures.

- Evidence log (1 mark): cite relation $a_c = v^2/r$ and $g = 9.8\ \text{m/s}^2$.
  Scoring: accept small rounding differences; if student shows steps clearly, full credit.

8. (5 marks) Exemplar:

- Chain (3 marks): 1) Axiom: gravitational force depends on mass and distance. 2) The Moon pulls more strongly on the near side of Earth (closer) than on the far side; this difference in force across Earth produces tidal forces (differential gravity). 3) Differential pull creates two bulges: one toward the Moon (stronger pull) and one on the opposite side where Earth's center is pulled away relative to far-side water, producing bulge. Steps numbered.
- Assumption and bias audit (1 mark): e.g., "Assumption: Earth treated as uniform sphere and water responds freely; bias: neglects landmasses, ocean depth, resonance, and Earth's rotation — limits the model's accuracy." Explain how limitation affects predictions (e.g., local tide magnitudes differ).
- Evidence log (1 mark): cite observational fact that tides correlate with Moon position; relate to differential gravity concept.
  Scoring: require mention of differential force; accept qualitative explanation.

9. (5 marks) Exemplar:

- Critique (2 marks): Identify error: conflates mass with gravitational acceleration; heavier objects do not fall faster in a vacuum — acceleration due to gravity is independent of mass. Explain logically: gravitational force $F = m g$ increases with m, but acceleration $a = F/m = g$ (mass cancels).
- Corrected statement (2 marks): "Heavier and lighter satellites orbit at the same speed for a given orbit radius; the required orbital speed depends on orbital radius and central mass, not satellite mass." Provide simple justification using $a_c = v^2/r = GM/r^2$ (mass m cancels).
- Evidence mapping (1 mark):
  - Claim: Satellite orbital speed is independent of its mass.
  - Warrant: gravitational force ⊠ m, but acceleration = F/m so m cancels.
  - Backing: standard derivation $v = \sqrt{GM/r}$ or classical experiments showing equal fall times.
    Scoring: award partial if student gives correct conceptual critique but omits formal cancellation argument.

10. (5 marks) Exemplar table (award points for completeness):

- Claim: "Satellite at 500 km will remain in orbit ≥1 year without propulsion."
- Warrant/backing items (3+), effects, confidence:
  1. Atmosphere density at 500 km — backing: standard atmosphere models (near-zero but present) — effect: decreases lifetime via drag — confidence: M (depends on solar activity).
  2. Satellite cross-section & mass-to-area ratio — backing: satellite design specs — effect: larger

cross-section increases drag -> reduces lifetime — confidence: H if known.

3. Initial orbital speed / altitude stability — backing: launch insertion accuracy data — effect: sub-optimal speed can lower perigee into denser atmosphere -> reduces lifetime — confidence: M.

- Award 2 marks for table completeness, 2 marks for correct effect analyses, 1 mark for justified confidences.
  Scoring: accept plausible items and justified confidence levels; partial credit if fewer than three backing items with strong justification.

11. (6 marks) Exemplar derivation steps:

- Laws (2 marks): State gravitational law in formula form (for teacher grading: acceptable in words): $F_g = G M m / r^2$. State centripetal requirement: $F_c = m v^2 / r$.
- Algebra (3 marks): Set $F_g = F_c$ for circular orbit: $G M m / r^2 = m v^2 / r$. Cancel m: $G M / r^2 = v^2 / r$. Multiply both sides by r: $G M / r = v^2$. Take square root: $v = \sqrt{G M / r}$. Numbered steps and show cancellation of m.
- Evidence log (1 mark): cite Newton's law of gravitation and centripetal formula as backing.
  Scoring: full marks require correct cancellation and algebra; if student misses cancellation but obtains correct final expression, award partial.

12. (6 marks) Exemplar:
    (a) Compute g from $s = 1/2\, g t^2$ with s = 2.00 m and t = 0.64 s.

- Calculation (2 marks): $g = 2s / t^2 = (2 \times 2.00) / (0.64^2) = 4.00 / 0.4096 \approx 9.770$ m/s². (2 marks)

  (b) Three sources of bias (2 marks total, ~0.66 each):

  - Reaction-time error in timing (systematic human delay) — tends to over/under estimate time.
  - Air resistance (slows fall) — reduces measured acceleration relative to true g.
  - Height measurement error (incorrect drop height) — directly affects computed g.
    Provide brief explanation of how each skews result and whether it increases or decreases g estimate.
    (c) Recompute with $a_{eff} = g - 0.20 = 9.8 - 0.20 = 9.6$ m/s². Use $s = 1/2\, a_{eff} t^2 \rightarrow t = \sqrt{2s / a_{eff}} = \sqrt{4.00 / 9.6} = \sqrt{0.4166667} \approx 0.6455$ s. (2 marks)

- Evidence log: note that adding air resistance reduces effective acceleration by stated 0.20; confidence M unless measured.
  Scoring: award partial for arithmetic rounding; provide feedback if sign mistakes.

13. (6 marks) Exemplar response:

- Critique Model A (2 marks): Correct that atmospheric drag is a major cause of decay at low altitudes, but false to claim only below 1,000 km because solar activity and other perturbations can increase atmospheric density above 1,000 km temporarily; gravitational perturbations and third-body effects can alter orbit too.

- Model B strengths/weaknesses (2 marks):
  - Strengths: includes multiple mechanisms (drag, solar-driven atmosphere expansion, gravitational perturbations). Better matches observed satellite decay events.
  - Weaknesses: may overcomplicate if specific cases are solely drag-dominated; needs quantification.

- Defense with evidence (2 marks): cite examples: 1) Increased solar activity in 2003 and 2005 raised atmospheric density causing higher decay at higher altitude (Backing: space weather records) — confidence M/H. 2) Observations of orbital lifetime variation with satellite ballistic coefficient (mass/area) demonstrate drag effect — backing: satellite tracking data / textbook. Evidence log: include source names or class references.
  Scoring: accept reasonable evidence references; award partial for solid critique and defense.

14. (6 marks) Exemplar (student picks Q7):
    (A) Success mapping (3 marks): State Q7 lines where accuracy achieved: e.g., “Accuracy: numeric v = 7.90×10^3 m/s (line 4 of my solution) — correct to three significant figures; Justification: the algebraic substitution v = sqrt(gr) is shown in steps 1–3; Evidence: I cited a_c = v^2/r and g = 9.8 m/s² in evidence log line.” (Assign points if mapping clearly links).
    (B) DOK (3 marks): Q7 targets DOK 2–3: skill/concept (use formulas and algebra) and strategic thinking (connect centripetal acceleration with gravitational acceleration to estimate orbital speed). Explain why: requires carrying out multi-step algebra and interpreting result. (Award full if reasoning present.)
    Scoring: require explicit mapping to parts of student’s own solution; partial if vague.

15. (6 marks) Exemplar recommendation and reasoning:

- Recommendation: Place the telescope at Sun–Earth L2 (Rank 1: L2). (3 marks)
- Chain of evidence (3 items, 3 marks):
  1. Claim: L2 has a stable gravitational environment for deep-space pointing — Warrant: L2 is a semi-stable point where spacecraft can maintain relative position with small station-keeping -> Backing: widely used for space telescopes (e.g., JWST) and reduced Earth occultation. Evidence log: cite example JWST at L2; Confidence H.
  2. Claim: LEO requires frequent avoidance of Earth blockage and faces atmospheric drag and orbital debris — Warrant: at 500 km Earth blocks large portion of sky and drag requires station-keeping -> Backing: observation constraints and drag forcing orbit adjustments; Confidence M.
  3. Claim: L2 provides long uninterrupted views and low thermal variability — Warrant: constant Sun–Earth–spacecraft geometry reduces thermal cycling important for sensitive instruments -> Backing: mission design docs for L2 telescopes; Confidence H.

- Bias audit (1 mark): Note limitations: choice depends on cost, communication latency, servicing needs, and radiation environment (L2 may have higher cosmic ray exposure and no easy servicing — bias toward science priority over serviceability). State how changed data (e.g.,

need for in-person servicing) could favor LEO. Evidence log: list factors (radiation environment, servicing capability, mission budget) and confidence levels.
Scoring: accept well-argued recommendation with correct claims/warrants/backing; partial credit for LEO defense if student provides strong evidence—score according to rubric.

End of exam materials.