13.S: Gravitation (Summary)

Key Terms

action-at-a-distance force	type of force exerted without physical contact
aphelion	farthest point from the Sun of an orbiting body; the corresponding term for the Moon's farthest point f
apparent weight	reading of the weight of an object on a scale that does not account for acceleratic
black hole	mass that becomes so dense, that it collapses in on itself, creating a singularity at the center surroun
escape velocity	initial velocity an object needs to escape the gravitational pull of another; it is more accurately defined as the velocity energy
event horizon	location of the Schwarzschild radius and is the location near a black hole from within which no object
gravitational field	vector field that surrounds the mass creating the field; the field is represented by field lines, in which the direction of magnitude (or field strength) is inversely proportional to the spacing of the lines; other masses re
gravitationally bound	two object are gravitationally bound if their orbits are closed; gravitationally bound systems have a negati
Kepler's first law	law stating that every planet moves along an ellipse, with the Sun located at a focus of t
Kepler's second law	law stating that a planet sweeps out equal areas in equal times, meaning it has a constant a
Kepler's third law	law stating that the square of the period is proportional to the cube of the semi-major axis
neap tide	low tide created when the Moon and the Sun form a right triangle with Earth
neutron star	most compact object known—outside of a black hole itself
Newton's law of gravitation	every mass attracts every other mass with a force proportional to the product of their masses, inversely proportional to and with direction along the line connecting the center of mass of each
non-Euclidean geometry	geometry of curved space, describing the relationships among angles and lines on the surface of a sp
orbital period	time required for a satellite to complete one orbit
orbital speed	speed of a satellite in a circular orbit; it can be also be used for the instantaneous speed for noncircular orbits ir
perihelion	point of closest approach to the Sun of an orbiting body; the corresponding term for the Moon's closest app
principle of equivalence	part of the general theory of relativity, it states that there no difference between free fall and being weightless, or a u acceleration
Schwarzschild radius	critical radius (R_S) such that if a mass were compressed to the extent that its radius becomes less than the Schwarzschil singularity, and anything that passes inside that radius cannot escape
space-time	concept of space-time is that time is essentially another coordinate that is treated the same way as any individual sp represent both special and general relativity, time appears in the same context as do the spati
spring tide	high tide created when the Moon, the Sun, and Earth are along one line
theory of general relativity	Einstein's theory for gravitation and accelerated reference frames; in this theory, gravitation is the result of mass and en is also often referred to as Einstein's theory of gravity
tidal force	**difference** between the gravitational force at the center of a body and that at any other location on the body; t
universal gravitational constant	constant representing the strength of the gravitational force, that is believed to be the same throu

Key Equations

Newton's law of gravitation	$\vec{F}_{12} = G\frac{m_1 m_2}{r^2}\hat{r}_{12}$
Acceleration due to gravity at the surface of Earth	$g = G\frac{M_E}{r^2}$
Gravitational potential energy beyond Earth	$U = -\frac{GmM_E}{r}$
Conservation of energy	$\frac{1}{2}mv_1^2 - \frac{GMm}{r_1} = \frac{1}{2}mv_2^2 - \frac{GMm}{r_2}$
Escape velocity	$v_{esc} = \sqrt{\frac{2GM}{R}}$
Orbital speed	$v_{orbit} = \sqrt{\frac{GM_E}{r}}$
Orbital period	$T = 2\pi\sqrt{\frac{r^3}{GM_E}}$
Energy in circular orbit	$E = K + U = -\frac{GmM_E}{2r}$
Conic sections	$\frac{\alpha}{r} = 1 + e\cos\theta$

Kepler’s third law	$T^2 = \frac{4\pi^2}{GM}a^3$
Schwarzschild radius	$R_S = \frac{2GM}{c^2}$

Summary

13.1 Newton's Law of Universal Gravitation

- All masses attract one another with a gravitational force proportional to their masses and inversely proportional to the square of the distance between them.
- Spherically symmetrical masses can be treated as if all their mass were located at the center.
- Nonsymmetrical objects can be treated as if their mass were concentrated at their center of mass, provided their distance from other masses is large compared to their size.

13.2 Gravitation Near Earth's Surface

- The weight of an object is the gravitational attraction between Earth and the object.
- The gravitational field is represented as lines that indicate the direction of the gravitational force; the line spacing indicates the strength of the field.
- Apparent weight differs from actual weight due to the acceleration of the object.

13.3 Gravitational Potential Energy and Total Energy

- The acceleration due to gravity changes as we move away from Earth, and the expression for gravitational potential energy must reflect this change.
- The total energy of a system is the sum of kinetic and gravitational potential energy, and this total energy is conserved in orbital motion.
- Objects must have a minimum velocity, the escape velocity, to leave a planet and not return.
- Objects with total energy less than zero are bound; those with zero or greater are unbounded.

13.4 Satellite Orbits and Energy

- Orbital velocities are determined by the mass of the body being orbited and the distance from the center of that body, and not by the mass of a much smaller orbiting object.
- The period of the orbit is likewise independent of the orbiting object’s mass.
- Bodies of comparable masses orbit about their common center of mass and their velocities and periods should be determined from Newton’s second law and law of gravitation.

13.5 Kepler's Laws of Planetary Motion

- All orbital motion follows the path of a conic section. Bound or closed orbits are either a circle or an ellipse; unbounded or open orbits are either a parabola or a hyperbola.
- The areal velocity of any orbit is constant, a reflection of the conservation of angular momentum.
- The square of the period of an elliptical orbit is proportional to the cube of the semi-major axis of that orbit.

13.6 Tidal Forces

- Earth’s tides are caused by the difference in gravitational forces from the Moon and the Sun on the different sides of Earth
- Spring or neap (high) tides occur when Earth, the Moon, and the Sun are aligned, and neap or (low) tides occur when they form a right triangle.
- Tidal forces can create internal heating, changes in orbital motion, and even destruction of orbiting bodies.

13.7 Einstein's Theory of Gravity

- According to the theory of general relativity, gravity is the result of distortions in space-time created by mass and energy.
- The principle of equivalence states that that both mass and acceleration distort space-time and are indistinguishable in comparable circumstances.
- Black holes, the result of gravitational collapse, are singularities with an event horizon that is proportional to their mass.
- Evidence for the existence of black holes is still circumstantial, but the amount of that evidence is overwhelming.

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