Chapter 6
Equilibrium and Elasticity

6.1. Equilibrium

6.2. The Center of Gravity and Conditions for Stable Equilibrium

6.3. Elasticity

6.1. Equilibrium

The term equilibrium implies either that the object is at rest or that its center of mass moves with constant velocity

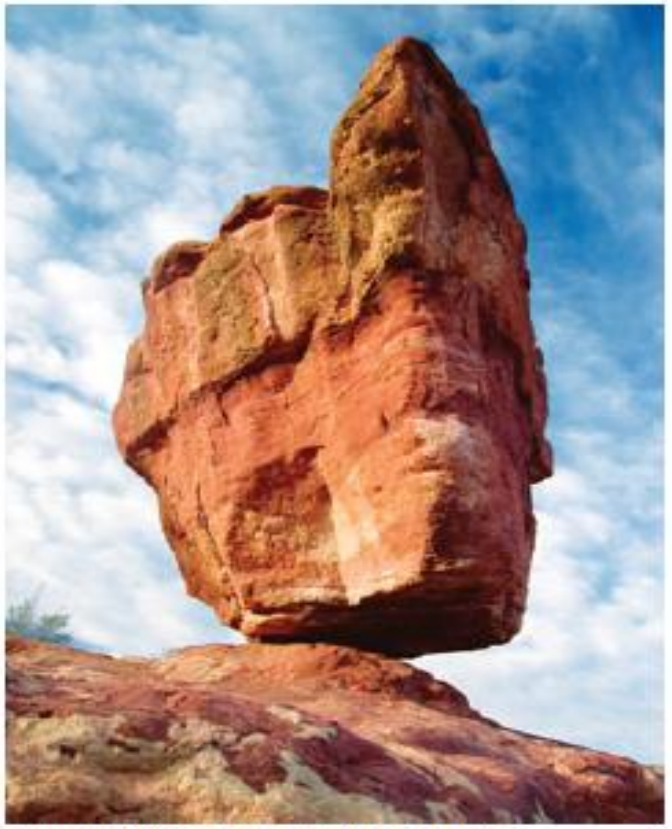
Examples:

(1)a book resting on a table,

(2)a hockey puck sliding with constant velocity across a frictionless surface,

(3) the rotating blades of a ceiling fan, and

(4) the bicycle traveling along a straight path at constant speed.



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A balancing rock

a. The requirements of Equilibrium of the objects:

1. The linear momentum $\vec{P}$ of its center of mass (COM) is constant.

$\vec{P}$ is a constant $\quad \vec{F}_{net} = \frac{d\vec{P}}{dt} = 0$

2. Its angular momentum $\vec{L}$ about its COM, or about any other point is also a constant.

$\vec{L}$ is a constant $\quad \vec{\tau}_{net} = \frac{d\vec{L}}{dt} = 0$

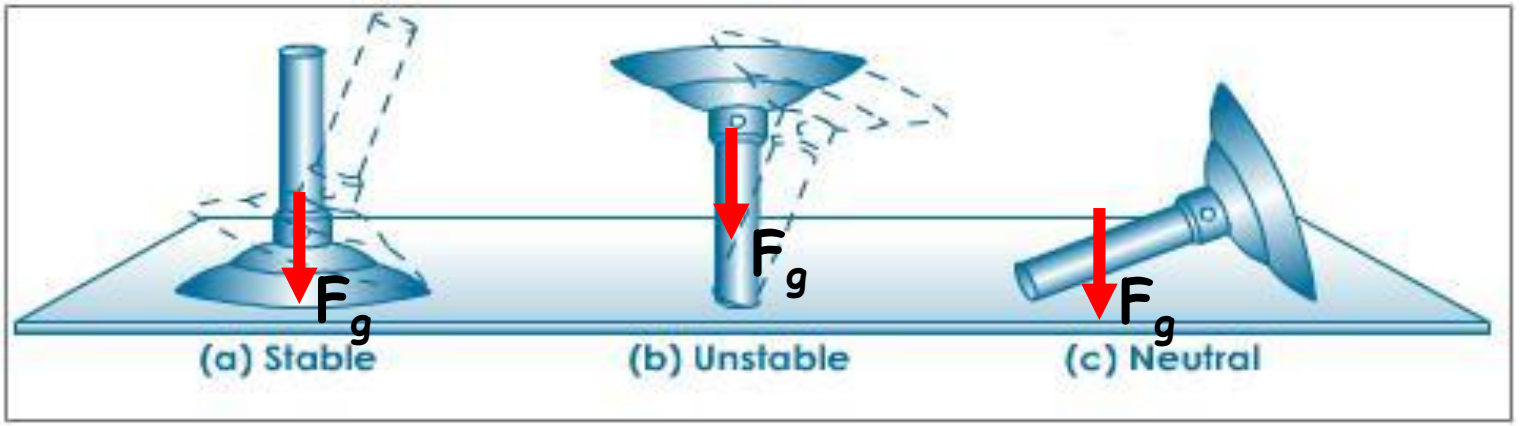
b. Static equilibrium:

Objects are not moving either in translation or in rotation.

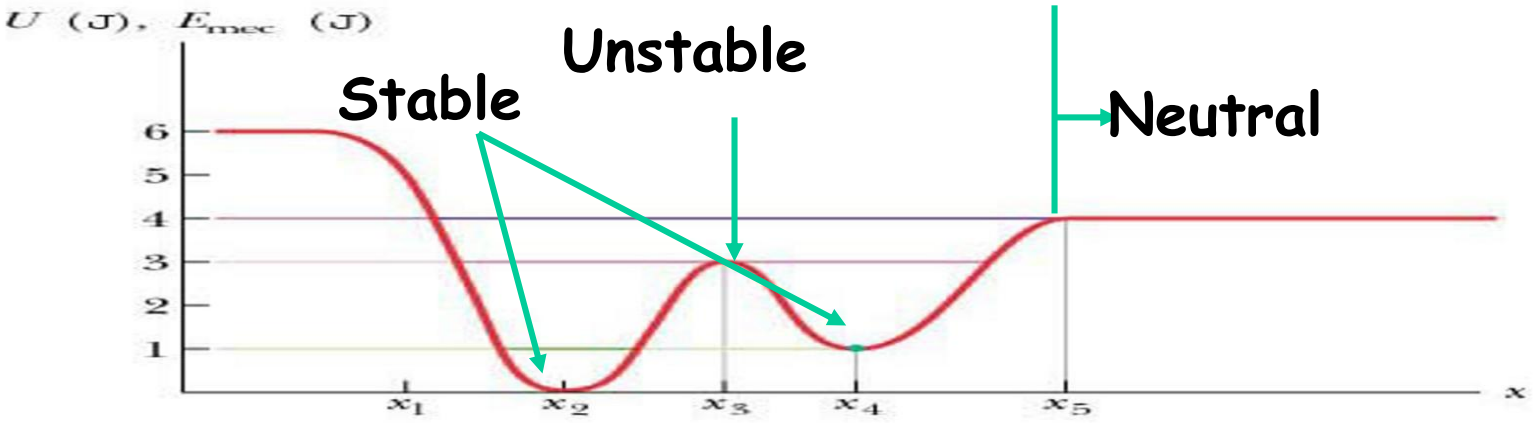
Three states of static equilibrium: neutral, stable, and unstable:

- **Stable Equilibrium:** An object can returns to its equilibrium position after it has been displaced *slightly*.
- **Unstable Equilibrium:** An object does not return to its equilibrium position and does not remain in the displaced position after it has been displaced slightly.
- **Neutral Equilibrium:** A body stays in the displaced position after it has been displaced slightly.

Equilibrium of a Bunsen burner



Potential Energy Curve



6.2. The Center of Gravity and Conditions for Stable Equilibrium

·**Center of Gravity (COG):** The point of a body at which the gravitational force can be considered to act.

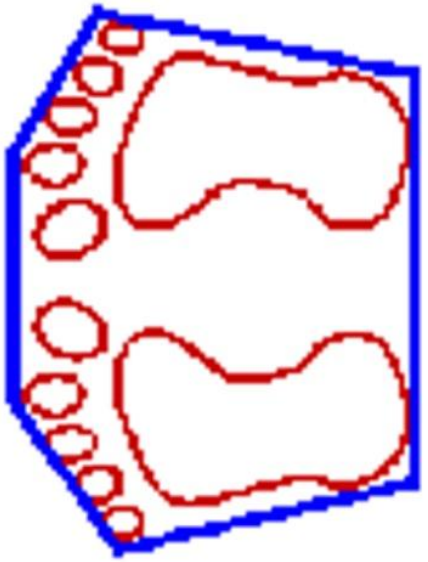
If the gravitational acceleration *g* is the same for all elements of a body, then the body's *COG* is coincident with its *COM*.

·Recall Center of Mass (COM): $\vec{r}_{com} = \frac{1}{M}\sum_{i=1}^{n} m_i \vec{r}_i$

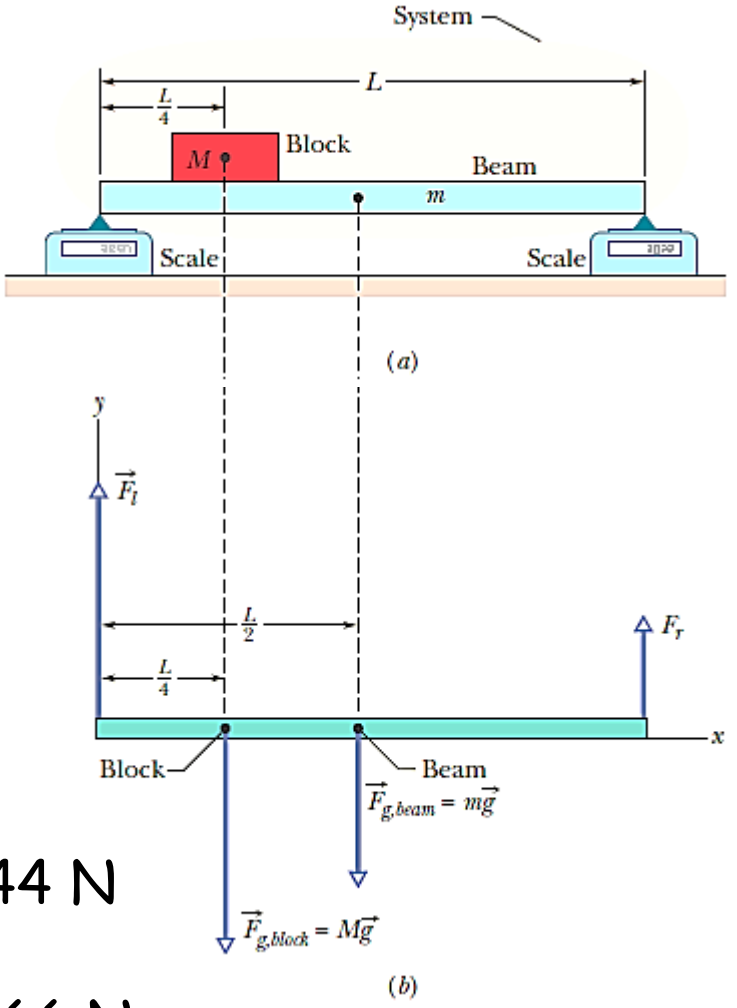
·**Base of Support:** It is the area formed by a perimeter around the supporting parts of an object in balance on a surface.

·Conditions for Stable Equilibrium:

- The body should have a broad base of support.
- *COG* of the body should be as low as possible.
- Vertical line drawn from the center of gravity should fall within the base of support.



Example: a uniform beam, of length L and mass m = 1.8 kg, is at rest on two scales. A uniform block, with mass M = 2.7 kg, is at rest on the beam, with its center a distance $L/4$ from the beam's left end. What do the scales read?



The forces have no x components, we consider to the y components,

Balance of Force on y component:

$$F_{net,y} = 0$$

$$F_l + F_r - Mg - mg = 0 \qquad (1)$$

Balance of Torque:

$$\tau_{net,z} = 0$$

$$(0)(F_l) - (L/4)(Mg) - (L/2)(mg) + (L)(F_r) = 0 \qquad (2)$$

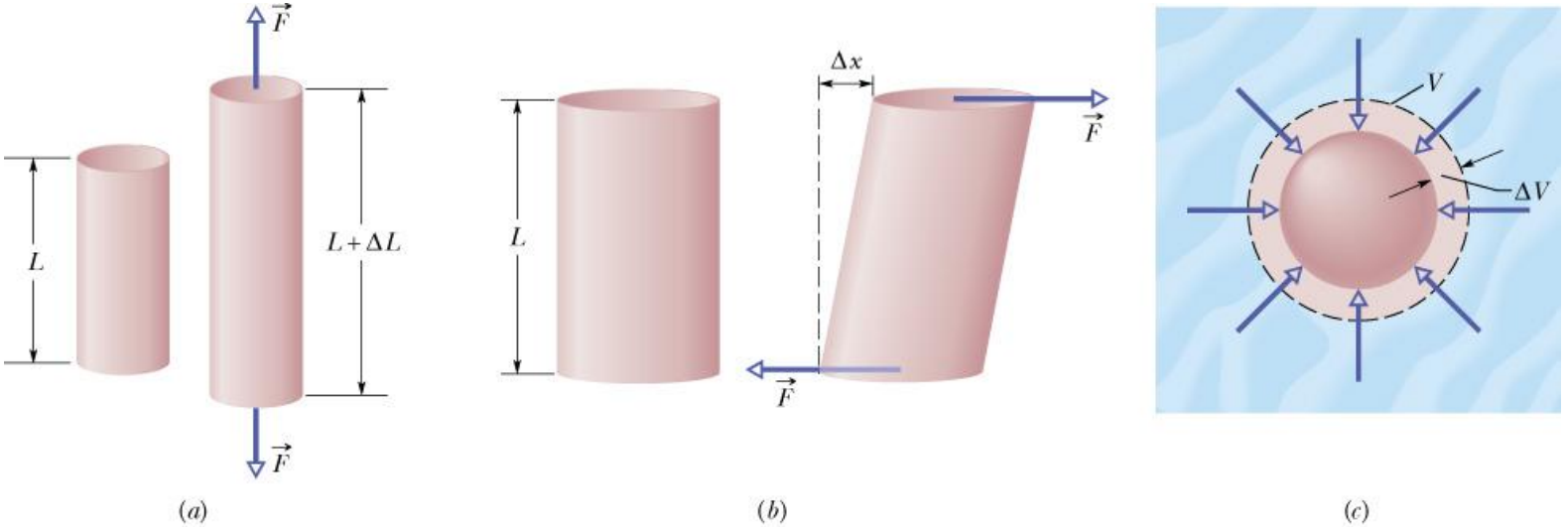
Therefore:

$F_r = 1/4\ Mg + 1/2\ mg = (\frac{1}{4}2.7 + \frac{1}{2}\ 1.8) \times 9.8 = 15.44$ N

$F_l = (M + m)g - F_r = (2.7 + 1.8) \times 9.8 - 15.44 = 38.66$ N

6.3. Elasticity

It is the physical property of a material that returns to its original shape once deforming forces (stress) are removed.



Tensile stress **Shearing stress** **Hydraulic stress**

Read text (p. 315-318)

Chapter 7 Gravitation

7.1. Newton's Law of Gravitation
7.2. Kepler's Laws
7.3. Gravitational Lensing Effect

7.1. Newton's Law of Gravitation

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

The tendency of bodies to move toward one another.

$G=6.67\times10^{-11}$ N m^2/kg^2: the gravitational constant

Gravitation Near Earth's Surface

$$F = G\frac{Mm}{r^2}$$

gravitational acceleration $g = G\frac{M}{r^2}$

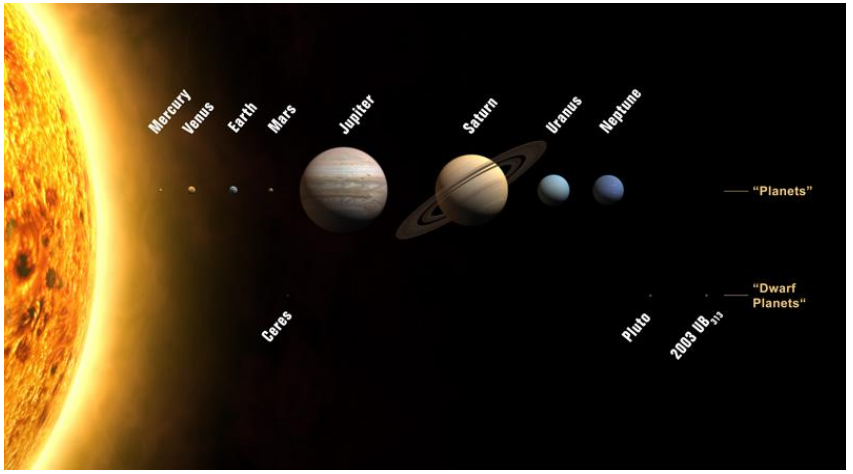
$$\Rightarrow F = mg$$

Gravitational Potential Energy:

$$U = -\frac{GMm}{r}$$

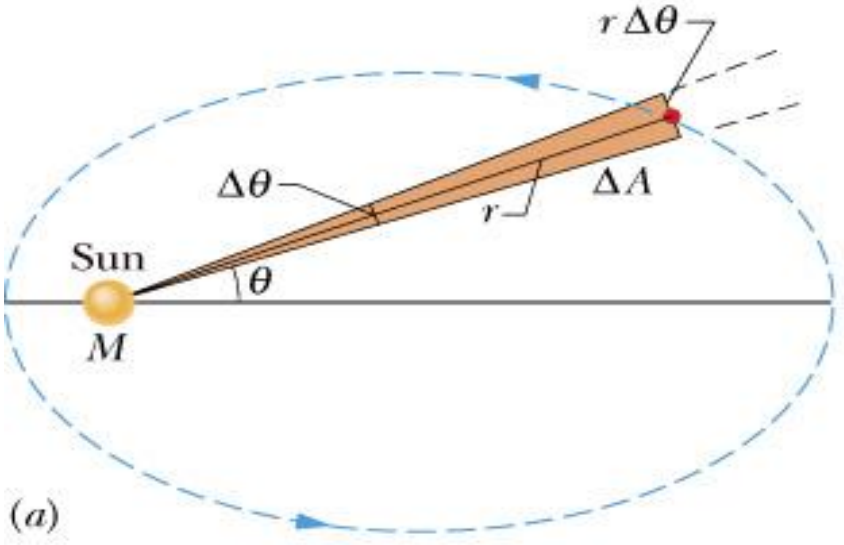
$$U = 0 \text{ for } r = \infty$$

7.2. Kepler's Laws



1. **The law of orbits:** All planets move in elliptical orbits, with the Sun at one focus.

2. **The law of areas:** the rate dA/dt at which it sweeps out area A is constant. (A line that connects a planet to the Sun sweeps out equal areas in the plane of the planet's orbit in equal time intervals)



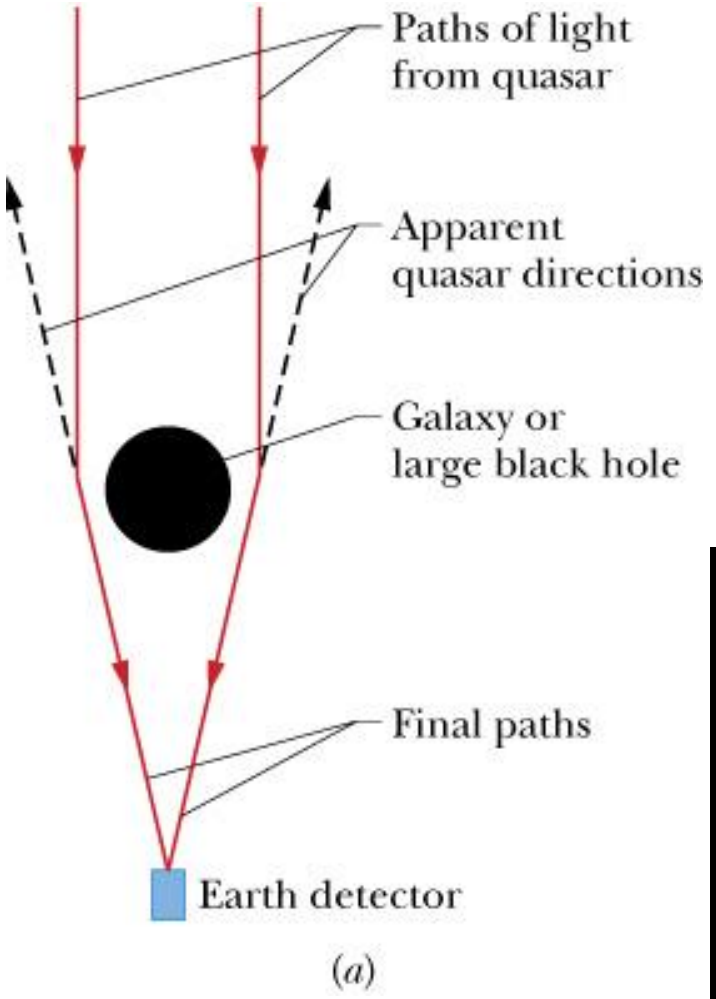
3. **The law of periods:** The square of the period of any planet is proportional to the cube of the semi-major axis of its orbit.

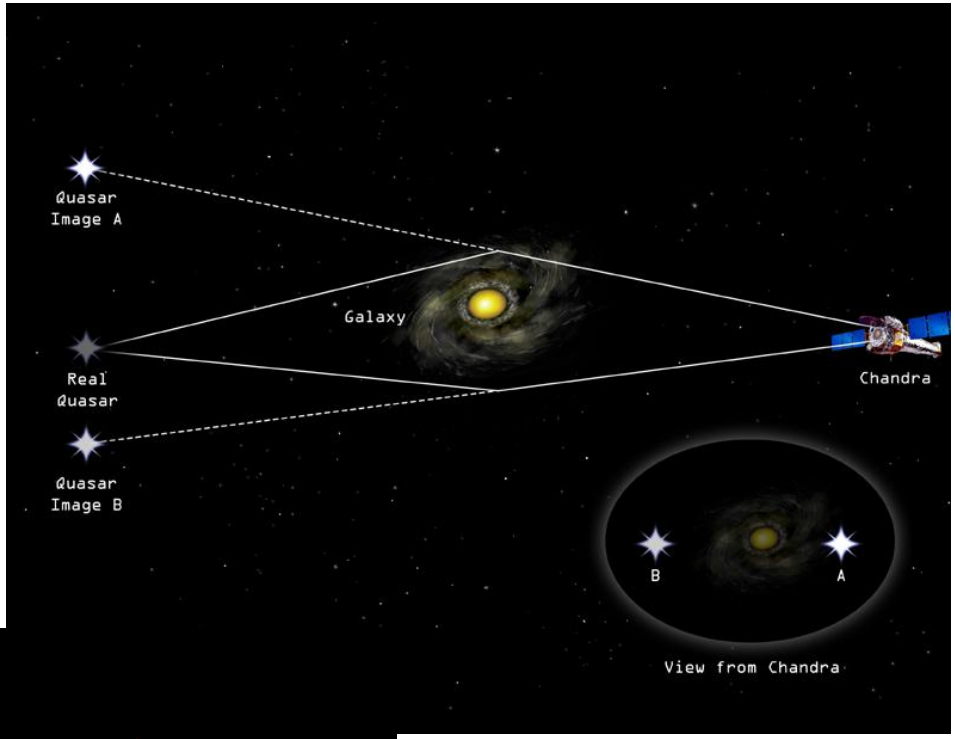
$$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$$

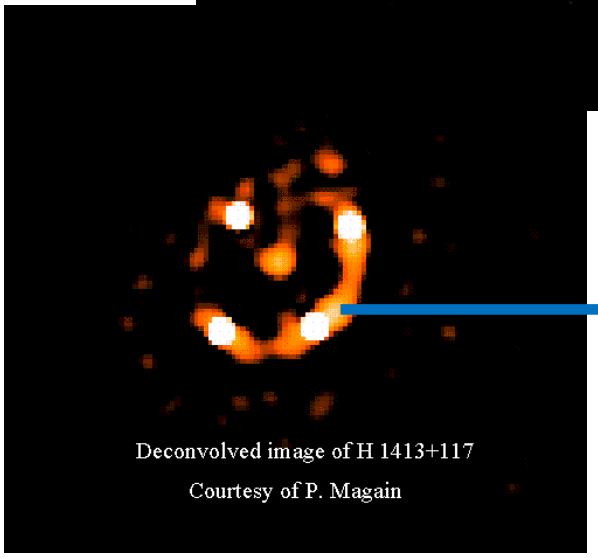
https://www.youtube.com/watch?v=s77LJO6USEY

7.3. Gravitational Lensing Effect

According to Einstein's general theory of relativity, when light passes near a massive object (e.g., Earth), the path of the light bends slightly because of the curvature of space there. This effect is called Gravitational Lensing.







Einstein's ring