Quantifying Gravity Across Celestial Objects

List of Gravitational Pull Approximate Values

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1 Analysis of Gravitational Acceleration Among Different Celestial Bodies

Table 1: Calculated and Approximate Surface Gravity Values for Selected Celestial Bodies

Planet / Moon	Mass M (kg)	Radius R (m)	Calculated g (m/s^2)	Approx. g (m/s^2)
Betelgeuse	3.2808×10^{31}	5.3151×10^{11}	0.007751	0.0076
KW Sagittarii	5.9652×10^{31}	7.0196×10^{11}	0.008079	0.0080
Moon	7.3476×10^{22}	1.7374×10^{6}	1.625383	1.62
Mercury	3.3011×10^{23}	2.4397×10^{6}	3.701617	3.70
Mars	6.4169×10^{23}	3.3895×10^{6}	3.727861	3.73
Uranus	8.6810×10^{25}	2.5559×10^{7}	8.869267	8.86
Venus	4.8673×10^{24}	6.0518×10^{6}	8.870022	8.87
Earth	5.9722×10^{24}	6.3781×10^{6}	9.798450	9.80
Saturn	5.6834×10^{26}	6.0268×10^{7}	10.44336	10.44
Neptune	1.0241×10^{26}	2.4764×10^{7}	11.14458	11.15
Jupiter	1.8982×10^{27}	7.1492×10^{7}	24.78750	24.79
Sirius A	4.1020×10^{30}	1.1903×10^{7}	193.22636	193
Sun	1.9884×10^{30}	6.957×10^{8}	274.19871	274
Proxima Centauri	2.4278×10^{29}	1.0727×10^{8}	1408.02889	1408
Sirius B	2.0241×10^{30}	5.8428×10^{6}	3.957×10^{6}	3.95×10^{6}
Vela Pulsar	2.6843×10^{30}	9.6560×10^{3}	1.92153×10^{12}	1.92×10^{12}

From this table, it is quite clear that among all the planetary objects we chose to calculate gravity for, the red supergiant Betelgeuse has the lowest surface gravity. It is so weak that we would not even feel any pull if we were standing on its surface. KW Sagittarii has almost the same gravity as Betelgeuse. Interestingly, Mercury and Mars also have nearly equal surface gravity, even though their masses and radii are completely different.

Other celestial bodies show a significant amount of gravitational pull, but for Sirius B and the Vela Pulsar, the surface gravity is truly enormous. Despite KW Sagittarii and Betelgeuse being much more massive and larger in size than the Vela Pulsar, the pulsar still has the strongest gravitational pull. This clearly demonstrates that gravity depends on both an object's mass and radius, and it can vary widely from one celestial body to another — something we can clearly observe from this table.

2 Limitations and Refinements

We should remember that the surface gravity values calculated earlier are only rough estimates. In those calculations, we assumed that each planet or moon is a perfect sphere with mass evenly distributed. In reality, celestial bodies have mountains, valleys, oceans, and uneven mass distributions, which can slightly affect gravity at different locations. Additionally, we used average masses and radii for stars and planets, so the actual surface gravity may vary depending on the values used. For example, we assumed the radius of Betelgeuse is $764\,R_\odot$, but the exact value is uncertain because these stars are extremely distant. Some rotate rapidly, and others cannot be directly observed even with telescopes. Astronomers determine masses and radii using indirect methods, so different values will yield slightly different surface gravity results, though all will be close to the estimated values.

Another factor that affects surface gravity is the planet's spin. A spinning planet creates a force that slightly reduces gravity at the equator. We can account for this with the formula:

$$g_{\text{eff}} = \frac{GM}{R^2} - \omega^2 R \cos^2\theta \tag{1}$$

Here, g_{eff} is the effective gravity at latitude θ, M is the mass of the planet, R is the radius, and ω is the planet's rotation speed. At the equator, $\theta = 0°$, so it becomes:

$$g_{\text{equator}} = \frac{GM}{R^2} - \omega^2 R \tag{2}$$

For example, for Earth ($M = 5.97 \times 10^{24}\,\text{kg}$, $R = 6.37 \times 10^6\,\text{m}$, $\omega = 7.29 \times 10^{-5}\,\text{rad/s}$), we get:

$$g_{\text{Earth, equator}} = \frac{(6.6743 \times 10^{-11})(5.9722 \times 10^{24})}{(6.3781 \times 10^6)^2} - (7.29 \times 10^{-5})^2 (6.3781 \times 10^6) \tag{3}$$

$$\therefore g_{\text{Earth, equator}} \approx 9.78\,\text{m/s}^2$$

This is a bit lower than the standard $9.81\,\text{m/s}^2$ because Earth's spin slightly reduces gravity at the equator.

We can use this adjustment for other planets and moons too, to get a more accurate value for surface gravity across the solar system.