



**Final
EXAMINATION
December 2018**

DURATION: 3 HOURS

No. of Students: 145

Department Name & Course Number: **Physics, PHYS 1901 - Sections A and T**

Course Instructor: **K. Moats**

AUTHORIZED MEMORANDA

None

Students MUST count the number of pages in this examination question paper before beginning to write, and report any discrepancy to a proctor. This question paper has 24 pages (including the cover page).

This examination question paper MAY NOT be taken from the examination room.

**In addition to this question paper, students require: an examination booklet
a scantron sheet**

yes **no**
yes **no**

Please print your name and student number in the boxes below:

Family Name	First Name	Student Number

This exam consists of One Hundred (100) multiple-choice questions. Answer all questions on the scantron sheet provided.

An equation sheet and tables of physical constants and astronomical data are provided at the end of this exam question paper.

1. Testing is important to developing:
 - A) a hypothesis
 - B) a theory
 - C) a pseudoscience
 - D) myths

2. While watching a star, you see that it moves 15 degrees across the sky. How long have you been watching it?
 - A) 1 hour
 - B) 3 hours
 - C) 15 minutes
 - D) 1 minute

3. The places where the Sun crosses the celestial equator are called the:
 - A) prime meridians
 - B) zeniths
 - C) equinoxes
 - D) solstices

4. When the Moon is directly opposite the Sun in the sky, its phase is:
 - A) new
 - B) waxing or waning crescent
 - C) first or third quarter
 - D) full

5. A lunar eclipse can only happen during a:
 - A) new Moon
 - B) solstice
 - C) first quarter Moon
 - D) full Moon

6. What conditions are necessary for a partial solar eclipse?
- A) New Moon on the ecliptic, with the observer in its penumbral shadow
 - B) Full Moon on the celestial equator, with the observer in its umbral shadow
 - C) Full Moon at apogee
 - D) First or third quarter Moon at a node
7. Which of these observations of Galileo refuted Ptolemy's epicycles?
- A) The complete cycle of Venus' phases
 - B) The rotation of sunspots across the Sun's surface
 - C) The revolution of Jupiter's moons around it
 - D) The craters on the Moon
8. Which was a contribution to astronomy made by Copernicus?
- A) The planets move around the Sun in elliptical orbits
 - B) His theory of gravity accounted for the variable speeds of the planets
 - C) He laid out the order and relative motion of the known solar system
 - D) His telescope revealed the four moons of Jupiter, a model solar system
9. Which of the following concepts was **NOT** a part of Kepler's Laws of Planetary Motion?
- A) All planetary orbits are ellipses
 - B) The square of a planet's orbital period is equal to the cube of its average distance
 - C) An imaginary line from a planet to the Sun traces out equal areas in equal time intervals
 - D) Epicycles are needed to explain the varying brightness of the planets
10. Tycho Brahe's contribution to Kepler's Laws of Planetary Motion was:
- A) his detailed and accurate observations of the planets' positions
 - B) his observations of Jupiter's moons
 - C) a mathematical explanation of epicycles
 - D) the correct explanation of lunar phases

11. Kepler's second law implies what about planetary motion?
- A) A planet moves at a constant speed during its orbit of the Sun
 - B) A planet moves slower when it is closer to the Sun
 - C) A planet moves faster when it is closer to the Sun
 - D) This law implies nothing about a planet's motion
12. The force of gravity between two objects:
- A) increases with the masses of the bodies, but decreases with their separations
 - B) increases with the masses of the bodies, but decreases with the square of the distance between them
 - C) increases with the square of their masses, but decreases with the cube of their periods of orbit about the Sun
 - D) depends on the density, not the mass of the bodies
13. If an electromagnetic wave's wavelength doubles, its speed:
- A) is halved
 - B) is also doubled
 - C) is unchanged
 - D) is now 4 times smaller
14. Which of the following types of electromagnetic radiation has the shortest wavelength?
- A) Gamma rays
 - B) Radio
 - C) Visible light
 - D) Ultraviolet
15. Colours of visible light appear different to us because of their photons' different:
- A) speeds
 - B) amplitudes
 - C) frequencies
 - D) magnetic fields

16. There are no X-ray telescopes on Earth because:
- A) they are too expensive to build
 - B) no one has yet invented an X-ray telescope that works
 - C) there are no astronomical objects that emit X-rays
 - D) X-rays don't penetrate Earth's atmosphere
17. Star A has a temperature that is half the temperature of star B. Which statement below is correct?
- A) Star A is redder than star B
 - B) Star A is bluer than star B
 - C) Star A and star B have the same colour
 - D) Star A is redshifted and star B is blueshifted
18. The light from an object moving tangentially (to your left or right) will exhibit:
- A) a blueshift
 - B) a redshift
 - C) no shift in wavelength
 - D) motion faster than the speed of light
19. The dark lines in the Sun's spectrum are actually:
- A) emission lines from hot gases in the chromosphere of the Sun
 - B) absorption lines due to the thin outer layer above the photosphere
 - C) redshifted lines due to the Sun's rotation
 - D) caused by sunspots
20. The classical model of the hydrogen atom that explains its spectral line structure is due to:
- A) Kirchhoff
 - B) Bohr
 - C) Kepler
 - D) Newton

21. Of the following types of electromagnetic radiation, which has the lowest energy?
- A) Radio
 - B) Visible
 - C) Ultraviolet
 - D) X-ray
22. If the rest wavelength of a certain spectral line is 600 nm, but we observe it at 594 nm, then:
- A) the source is approaching us
 - B) the source is receding from us
 - C) the source is getting hotter as we watch
 - D) the source is spinning very rapidly
23. What information about an astronomical object can be determined by observing its spectrum?
- A) Its temperature
 - B) Its radial motion
 - C) Its chemical composition
 - D) All of the above
24. What is the primary purpose of an optical telescope?
- A) To magnify and make distant objects appear closer
 - B) To separate light into its component colours
 - C) To access wavelengths that we cannot see visually
 - D) To collect a lot of light and bring it to a focus
25. The major advantage of a Newtonian reflector over a refractor is:
- A) its compact size
 - B) the elimination of chromatic aberration
 - C) there are only two lenses to grind
 - D) the central hole in the mirror is smaller

26. The amount of diffraction, and thus the resolution of a telescope, depends upon:
- A) the wavelength used and the size of the main telescope objective lens or mirror
 - B) whether the telescope is a reflector or refractor
 - C) the brightness of the object
 - D) the size and sensitivity of the CCD chip used for imaging
27. A small telescope has _____ light-gathering power when compared to a large telescope.
- A) less
 - B) more
 - C) the same
 - D) chromatic
28. What problem is adaptive optics designed to correct?
- A) Light pollution
 - B) Slight tracking errors in trying to compensate for Earth's unsteady rotation
 - C) The effects of atmospheric turbulence
 - D) The absorption of ultraviolet by the ozone layer
29. Radio dishes are large in order to:
- A) attract funding from NASA
 - B) improve their angular resolution and collect the very weak radio photons
 - C) give greater magnification
 - D) detect shorter waves than optical telescopes for superior resolution
30. Which of the following greatly improves the angular resolution of radio maps?
- A) More sensitive spectrometers
 - B) Switching from photographic plates to CCD imaging
 - C) The use of interferometers
 - D) Chilling the infrared detectors

31. The rotation periods of Venus, Jupiter, Saturn, Uranus and Neptune are difficult to determine because:
- A) they rotate so fast
 - B) they are all gas giants
 - C) they are so far away from the Sun
 - D) their surface features are obscured by their atmospheres
32. Planetary orbits:
- A) are evenly spaced throughout the solar system
 - B) are highly inclined to the ecliptic
 - C) are almost circular, having low eccentricities
 - D) have the Sun at their exact centre
33. Which of the characteristics listed below describe the terrestrial planets?
- A) Having rings and many moons
 - B) Large and gaseous
 - C) Small, dark and icy
 - D) Possessing weak magnetic fields
34. Which of the characteristics listed below describe the Jovian planets?
- A) Close to the Sun
 - B) Low densities
 - C) Small masses
 - D) Slow rotational periods
35. In terms of axial tilt, which of the Jovian planets shows us the largest inclination?
- A) Jupiter
 - B) Saturn
 - C) Uranus
 - D) Neptune

36. As the solar nebula contracts due to gravitation, the cloud:
- A) spins faster
 - B) expands
 - C) becomes more spherical in shape
 - D) changes direction of motion
37. What was the primary role of dust in the formation of the solar system?
- A) Dust formed the rings around Uranus, Neptune, and Jupiter
 - B) Dust acted as condensation nuclei: platforms to which other particles could attach and form larger particles of matter
 - C) The Sun formed from a vast spinning cloud consisting only of dust
 - D) Dust provided the radioactive elements that initially heated the Sun
38. From the Earth's centre outward, the correct order is:
- A) core, magnetosphere, mantle, crust, hydrosphere, atmosphere
 - B) core, crust, mantle, hydrosphere, atmosphere, magnetosphere
 - C) magnetosphere, core, mantle, crust, hydrosphere, atmosphere
 - D) core, mantle, crust, hydrosphere, atmosphere, magnetosphere
39. Within Earth's atmosphere, in which layer does convection occur?
- A) The troposphere
 - B) The stratosphere
 - C) The mesosphere
 - D) Convection occurs in all layers of Earth's atmosphere
40. We determine the structure of the Earth's core using:
- A) deep mine shafts
 - B) satellite imaging
 - C) radar and sonar
 - D) seismic wave data

41. In noting that the Earth is “differentiated”, we mean that:
- A) the density of its materials decreases as you go downward toward the core
 - B) the Earth has evolved in a different pattern than any other planet
 - C) the iron and nickel core is denser than the silicate mantle and crust
 - D) radioactive heating in the core is at a slower pace than when the Earth was new
42. The presence of Earth’s magnetic field is a good indication that:
- A) a huge iron meteorite lies somewhere high up in the mantle, not in the core
 - B) the Earth has a liquid metal outer core, spinning rapidly as the Earth rotates
 - C) the Earth’s interior must be completely molten to the centre
 - D) the Earth’s interior has had time to solidify, with a rigid bar magnet created
43. At what lunar phase are the tides least noticeable?
- A) New Moon
 - B) Full Moon
 - C) Third quarter
 - D) Waxing crescent
44. Which of the following is **NOT** a factor in determining whether a body in the solar system retains an atmosphere?
- A) Composition and weight of the gases
 - B) Escape velocity
 - C) Distance from the Sun
 - D) Rotation rate
45. The lunar maria are found:
- A) anywhere large meteor impacts created deep basins
 - B) almost entirely on the far side of the Moon, which was more likely to be hit
 - C) almost entirely on the near side facing Earth, as the crust on the near side is thinner
 - D) not at all, since no liquid water really exists on the Moon

46. The average rate of erosion on the Moon is far less than on Earth because:
- A) the Moon lacks wind, water and an atmosphere
 - B) the crust of the Moon is much denser than the Earth's crust
 - C) the Moon is much younger than the Earth
 - D) the Moon's magnetic field protects it from the solar wind better than Earth's does
47. Which of these theories seems to best explain the Moon's origin?
- A) Impact Theory
 - B) Capture Theory
 - C) Co-formation Theory
 - D) Fission Theory
48. Which statement about the rotations of the Moon and Mercury is **FALSE**?
- A) Our Moon is in a 1:1 synch with the Earth, keeping the same side toward us
 - B) Mercury is in a 3:2 synch with the Sun, with the same side facing the Sun at every other perihelion
 - C) Like our Moon, Mercury does not rotate at all, keeping the same side facing the Sun
 - D) On the Moon, daytime lasts about 15 Earth days of constant sunlight
49. Mercury is very hard to observe from Earth because:
- A) it always appears as only half lit from Earth
 - B) it never gets more than 28 degrees from the Sun's glare
 - C) its elliptical orbit causes it to change speed unpredictably
 - D) its barren surface reflects too little sunlight; it is almost invisible always
50. Earth and Venus are often called sister planets. In which ways are they most alike?
- A) Atmospheric composition and density
 - B) Size, density, and surface gravity
 - C) Surface temperature and pressure
 - D) Polar caps and rusty red deserts

51. Through radar observations it was found that Venus':
- A) orbit around the Sun is speeding up
 - B) atmosphere is changing rapidly
 - C) rotation on its axis is retrograde
 - D) orbit around the Sun is in the clockwise sense
52. The atmospheric pressure on Venus:
- A) shows an extreme change with the seasons
 - B) is much lower than on Earth
 - C) is about the same as on Mercury
 - D) is much higher than on Earth
53. What is the result of the greenhouse effect on the surface environment of Venus?
- A) It has little or no effect
 - B) Its effect is about the same as on Earth
 - C) It has reduced the surface temperature by about 30 degrees Celsius
 - D) It has raised the surface temperature by hundreds of degrees Celsius
54. Mars is best viewed from Earth when it is at:
- A) perihelion
 - B) opposition
 - C) aphelion
 - D) none of the above
55. Unlike Earth, Mars' seasons are affected (enhanced and diminished) by the distance between Mars and the Sun. This is because:
- A) Earth is closer to the Sun to begin with
 - B) an Earth year is shorter
 - C) Mars is tilted more on its axis than Earth is
 - D) the orbit of Mars is significantly more elliptical

56. Evidence of liquid water in Mars' distant past suggests that it had a substantial atmosphere compared to what it has presently. What happened to its water vapor?
- A) Carbon dioxide in its atmosphere dissolved in the water on the surface and combined with surface rocks
 - B) Mars never had water vapor in its atmosphere, which was mostly hydrogen and helium
 - C) The water vapor froze into the polar ice caps and permafrost as Mars cooled
 - D) Mars initially had such a large greenhouse effect that the atmosphere became quite hot and slowly escaped
57. How do the atmospheres of Mars and Venus compare with each other?
- A) Both are chiefly carbon dioxide, but on Mars it can freeze as dry ice
 - B) Both are made of hydrogen and helium, like the Jovian planets
 - C) Like Earth, nitrogen is the chief atmospheric gas for both Mars and Venus
 - D) Both are rich in oxygen
58. Jupiter is noticeably oblate because:
- A) it has a strong magnetic field
 - B) it has such powerful gravity
 - C) it rotates rapidly
 - D) it undergoes a gravitational attraction from each of its various moons
59. How does the radius of Jupiter compare with that of the other planets?
- A) It is similar to the radius of Earth or Venus
 - B) It is larger than the radius of Uranus, but smaller than the radius of Saturn
 - C) It is larger than any other planet in our solar system
 - D) It is similar to Mercury's radius
60. The most striking "cloudmark" in Jupiter's atmosphere is the:
- A) Great Dark Spot
 - B) Cassini Division
 - C) Brown Dwarf
 - D) Great Red Spot

61. Alternating regions of rising and sinking gas in Jupiter's atmosphere:
- A) create light and dark bands
 - B) produced the ring system discovered by *Voyager*
 - C) generate their own magnetic fields
 - D) circle the planet from pole to pole
62. Jupiter gives back into space twice the energy it gets from the distant Sun. Where is this energy coming from, for the most part?
- A) The impact energy of comets like Shoemaker-Levy 9
 - B) Helium rain descending into its mantle and core
 - C) The slow escape of gravitational energy left from its formation
 - D) The combined tidal stress of all four large Galilean moons
63. What is the source of Jupiter's strong magnetic field?
- A) Charged particles trapped in Jupiter's solid iron core, similar to Earth's
 - B) Liquid metallic hydrogen swirling in the rapidly spinning mantle
 - C) The ionized sulfur ejected into a torus around Jupiter by Io
 - D) The auroral displays in the polar regions, just like with Earth
64. What is thought to be the cause of Io's volcanoes?
- A) Jupiter's magnetosphere and its charged particles
 - B) Tidal stresses from both Jupiter and the other Galilean moons
 - C) Solar radiation
 - D) Radioactive decay in Io's interior
65. The liquid layer in Europa is composed primarily of:
- A) ethane, similar to Neptune's moon Triton
 - B) water, similar to Earth's oceans
 - C) molten rock, similar to Earth's mantle
 - D) liquid hydrogen, similar to the region below Jupiter's atmosphere

66. Which of the Jovian moons is the largest, and is also the largest moon in the solar system, even bigger than Mercury?
- A) Titan
 - B) Triton
 - C) Ganymede
 - D) Callisto
67. If you could find a bathtub big enough for Saturn, the planet would:
- A) precipitate more helium
 - B) float
 - C) explode due to its liquid metallic hydrogen
 - D) sink due to its metallic interior
68. Saturn's cloud surface appears more uniform than Jupiter's because:
- A) due to Saturn's lower gravity, the colorful cloud layers escaped
 - B) it is composed of completely different gases than Jupiter's
 - C) the cloud layers are thicker, with fewer holes to see the colorful layers
 - D) due to Saturn's greater distance from the Sun, the colorful cloud layers are just not visible
69. Why does the atmosphere of Saturn appear to have only half the helium content of Jupiter?
- A) Because Saturn is so much colder, helium does not show up as strongly in its spectrum
 - B) Saturn was formed farther from the Sun, which is made mostly of helium
 - C) Jupiter fused some of its hydrogen into helium, while Saturn, a colder planet, has not
 - D) Much of Saturn's helium has differentiated towards its centre
70. The reason the rings of Saturn exist is because:
- A) the ring material lies within the Roche limit of Saturn
 - B) the gravitational influence of Titan confines them to those orbits
 - C) there has not been sufficient time for the ring particles to form a moon
 - D) Saturn's rapid rotation is spinning material away from its equator, out into space

71. Shepherd satellites are defined as:
- A) moons that confine a narrow ring
 - B) a type of moon that orbits another moon
 - C) moons that follow the exact orbit of another, larger, moon
 - D) moons that orbit inside the system of rings
72. Titan is an interesting moon because:
- A) beneath its clouds, Titan may be Earth-like, with liquid water
 - B) it has a rich atmosphere that may resemble that of the early Earth
 - C) the *Huygens* rover has sent back images of sedimentary rocks there
 - D) it is known to have ice volcanism on its surface
73. Adams and Leverrier predicted the position of Neptune, based on its perturbations of:
- A) Jupiter
 - B) the Sun
 - C) Saturn's rings
 - D) Uranus
74. Which of these is true about the seasons of Uranus?
- A) With a tilt of 29 degrees, they are not that different from Earth's solstices and equinoxes
 - B) Its strange tilt produces extreme seasonal variations, especially at the poles
 - C) At Uranus' equator, the Sun would always pass overhead every sixteen hours
 - D) There are no seasons at the poles
75. Neptune and Uranus have a bluish tint because:
- A) they are far away and distance makes objects appear blueshifted
 - B) their atmospheres contain methane, which absorbs red light
 - C) their atmospheres contain hydrogen and helium
 - D) ammonia ice reflects blue light better than any other colour

76. In the atmospheres of the Jovian planets, which component *decreases*, systematically, with distance from the Sun?
- A) Hydrogen
 - B) Helium
 - C) Methane
 - D) Ammonia
77. Which statement about the magnetic fields of Uranus and Neptune is **FALSE**?
- A) Neither fits the Dynamo model very well
 - B) Their magnetic fields are significantly tilted with respect to their rotational axes
 - C) Their magnetic fields pass directly through the cores of their planets, like all other fields
 - D) Both may have liquid ammonia replacing the liquid metallic hydrogen
78. What is the prediction for the future of Triton?
- A) It will provide the raw material for a future Neptunian ring
 - B) It will crash into Nereid when the smaller moon comes too close
 - C) Its orbit, while retrograde, is very stable and will not change
 - D) Its retrograde orbit will throw it back out into the Kuiper Belt again, with Pluto
79. How were the rings of Uranus discovered?
- A) Observations of the occultation of a star, made from Earth
 - B) By Percival Lowell, who observed two “bumps” on either side of Uranus
 - C) By *Voyager 2* when it passed by Uranus in 1986
 - D) By the *Hubble Space Telescope* in the infrared
80. The orbits of most asteroids:
- A) lie beyond Neptune
 - B) lie entirely beyond the orbit of Mars
 - C) cross the orbit of Earth
 - D) cross the orbits of all four terrestrial planets

81. The type of asteroid that would be the densest is:
- A) C-type
 - B) M-type
 - C) S-type
 - D) G-type
82. The orbits of most comets:
- A) are like the planets, fairly circular and in the ecliptic plane
 - B) are extremely elliptical and extend beyond the orbit of Neptune
 - C) go no farther out than Pluto, then return to the Sun again
 - D) are shorter than the 76 year period for Comet Halley
83. The tail of a comet always points:
- A) toward the Sun and disappears at perihelion
 - B) away from the Sun and becomes longest and brightest at perihelion
 - C) away from the Sun and disappears at perihelion
 - D) in the direction of the comet's motion
84. From its orbit, we now recognize Pluto as one of the largest members of the:
- A) moons of Neptune
 - B) asteroid belt
 - C) Kuiper Belt
 - D) Oort Cloud
85. When a formal definition of a planet in the solar system was adopted, Pluto was reclassified as a dwarf planet. What characteristic of planets does **NOT** describe Pluto?
- A) Planets orbit the Sun
 - B) Planets are approximately spherical
 - C) Planets have cleared the neighborhood around their orbit
 - D) Planets may have moons orbiting them

86. Meteor shower debris is believed to come from:
- A) the asteroid belt when Mars deflects it toward us annually
 - B) the core of a differentiated type M asteroid, now broken up
 - C) the crust of a differentiated type C asteroid, now broken up
 - D) the disintegration of a short period comet over many returns to the Sun
87. When searching for exoplanets, the radial velocity technique works best for:
- A) exoplanets whose orbits are along our line of sight (edge on)
 - B) exoplanets whose orbits are perpendicular to our line of sight (face on)
 - C) exoplanets whose orbits are nearly circular (low eccentricity)
 - D) exoplanets whose orbits are very eccentric (very elliptical)
88. When looking for the radial velocity changes detected due to Doppler shifts, which mass combination is most likely to be detected?
- A) high mass star, high mass planet
 - B) high mass star, low mass planet
 - C) low mass star, high mass planet
 - D) low mass star, low mass planet
89. When searching for exoplanets, the planetary transit technique works best for:
- A) exoplanets whose orbits are along our line of sight (edge on)
 - B) exoplanets whose orbits are perpendicular to our line of sight (face on)
 - C) exoplanets whose orbits are nearly circular (low eccentricity)
 - D) exoplanets whose orbits are very eccentric (very elliptical)
90. When we are lucky enough to see an extrasolar planet transit its star:
- A) it will cause the star to vanish for several hours
 - B) we can find the planet's size, mass, and density by the drop in light
 - C) we can determine what elements are in its atmosphere
 - D) we can be certain it is a terrestrial planet, not a Jovian planet

91. Why has direct imaging found so few exoplanets?
- A) Direct imaging is only possible using military satellites
 - B) Direct imaging only works if the planet is orbiting a bright star
 - C) Only a few attempts have been made to directly image an extrasolar planet
 - D) Exoplanets are faint and are usually close to their parent stars
92. Extrasolar planetary systems are similar to our solar system in all of the following ways, **EXCEPT**:
- A) that the exoplanets orbit in approximately the same plane
 - B) for the presence of hot Jupiters in some systems
 - C) that planets orbit in the same direction that their parent star rotates
 - D) None of them are dissimilar to our solar system
93. The habitable zone is the area around a star where:
- A) planets with life have been found
 - B) the greenhouse effect is possible
 - C) a planet could have an atmosphere
 - D) temperatures are suitable for planets to have liquid water
94. The light we see from the Sun comes from which layer?
- A) The chromosphere
 - B) The photosphere
 - C) The core
 - D) The corona
95. The area in the Sun's atmosphere located above the chromosphere (1,500-10,000 km) where the temperature rises dramatically is called the:
- A) photosphere
 - B) corona
 - C) transition zone
 - D) convection zone

96. By what mechanism does solar energy reach the Sun's photosphere from the layer just underneath it?
- A) Differentiation
 - B) Ionization
 - C) Radiation
 - D) Convection
97. Hydrostatic equilibrium in our Sun is the balance between:
- A) convection and radiation
 - B) convection and gravitation
 - C) pressure and radiation
 - D) gravitation and pressure
98. How long does the sunspot cycle last, on average?
- A) between 25 and 35 days
 - B) 365.25 days
 - C) about 11 years
 - D) about 76 years
99. Which of the following are **NOT** associated with sunspots?
- A) Granulation
 - B) Coronal mass ejections
 - C) Prominences
 - D) Solar flares
100. In the proton-proton cycle, the helium atom and neutrino have less mass than the original hydrogen. What happens to the "lost" mass?
- A) It is recycled back into hydrogen
 - B) It is ejected into space
 - C) It is converted to energy
 - D) It is transformed into electrons

Equation Sheet:

- Geometry of a circle:

$$\text{circumference} = 2 \pi \times \text{radius}$$

$$\text{area} = \pi \times \text{radius}^2$$

- Parallax and angular diameter:

$$1^\circ = 60' \quad 1' = 60''$$

$$\frac{\text{baseline}}{2 \pi \times \text{distance}} = \frac{\text{parallax}}{360^\circ}$$

$$\frac{\text{diameter}}{2 \pi \times \text{distance}} = \frac{\text{angular diameter}}{360^\circ}$$

- Elliptical Orbits:

$$\text{aphelion distance} = a(1 + e)$$

$$\text{perihelion distance} = a(1 - e)$$

- Kepler's 3rd Law:

$$P^2 \text{ (in Earth years)} = a^3 \text{ (in AU)}$$

- Newton's 2nd Law:

$$F = m a \quad W = m g$$

- Newton's Law of Gravity:

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

$$\text{where } G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$$

- Electromagnetic Waves:

$$\text{Period} = \frac{\lambda}{c}$$

$$f = \frac{1}{\text{Period}}$$

$$c = \lambda f$$

- Temperature:

$$\text{kelvins} = \text{degrees Celsius} + 273.15$$

- Wien's Law: $\lambda_{max} = \frac{2.9 \text{ mm}}{T}$

- Stefan-Boltzmann Law:

$$F = \sigma T^4$$

$$\text{where } \sigma = 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}$$

- Doppler Effect:

$$\lambda_{\text{apparent}} = \lambda_{\text{true}} \left(1 + \frac{v_r}{c}\right)$$

$$\text{Receding: } v_r > 0$$

$$\text{Approaching: } v_r < 0$$

- Hydrogen Atom:

$$E_n = 13.6 \left(1 - \frac{1}{n^2}\right) \text{ eV}$$

$$\text{where } 1 \text{ eV} = 1.6 \times 10^{-19} \text{ joule}$$

$$\text{Ground state: } n = 1$$

$$\text{Excited states: } n = 2, 3, 4, \dots$$

- Photon Energy:

$$E = h f$$

$$\text{where } h = 6.63 \times 10^{-34} \text{ joule seconds}$$

- Telescopes:

$$\text{Magnification} = \frac{f_{\text{objective}}}{f_{\text{eyepiece}}}$$

$$\text{angular resolution (")} = 0.25 \frac{\text{wavelength } (\mu\text{m})}{\text{diameter (m)}}$$

- Density: density = $\frac{\text{mass}}{\text{volume}}$

- Volume of a sphere: volume = $\frac{4}{3} \pi \text{ radius}^3$

- The Sun:

$$\text{Luminosity} = \text{Solar Constant} \times \text{Surface Area (at 1 AU)}$$

$$\text{Solar Constant} = 1400 \text{ W/m}^2$$

$$\text{Surface Area of a Sphere} = 4 \pi \text{ radius}^2$$

$$E = mc^2$$

Physical Constants

astronomical unit	1 AU = 1.496×10^8 km (1.5×10^8 km)
light-year	1 ly = 9.46×10^{12} km (10^{13} km, about 6 trillion miles)
parsec	1 pc = 3.09×10^{13} km = 206,000 AU = 3.3 ly
speed of light	$c = 299,792.458$ km/s (3×10^5 km/s)
Stefan-Boltzmann constant	$a = 5.67 \times 10^{-8}$ W/m ² · K ⁴
Planck's constant	$h = 6.63 \times 10^{-34}$ J s
gravitational constant	$G = 6.67 \times 10^{-11}$ Nm ² /kg ²
mass of Earth	$M_{\oplus} = 5.98 \times 10^{24}$ kg (6×10^{24} kg, about 6000 billion billion tons)
radius of Earth	$R_{\oplus} = 6378$ km (6500 km)
mass of the Sun	$M_{\odot} = 1.99 \times 10^{30}$ kg (2×10^{30} kg)
radius of the Sun	$R_{\odot} = 6.96 \times 10^5$ km (7×10^5 km)
luminosity of the Sun	$L_{\odot} = 3.83 \times 10^{26}$ W (4×10^{26} W)
effective temperature of the Sun	$T_{\odot} = 5772$ K (5800 K)
Hubble's constant	$H_0 = 70$ km/s/Mpc
mass of an electron	$m_e = 9.11 \times 10^{-31}$ kg
mass of a proton	$m_p = 1.67 \times 10^{-27}$ kg

* The rounded-off values used in the text are shown above in parentheses.

Unit Conversion Factors

Length		
1 angstrom (Å)	= 10^{-10} m	
1 nanometer (nm)	= 10^{-9} m	atomic physics, spectroscopy
1 micron (μm)	= 10^{-6} m	interstellar dust and gas
1 centimeter (cm)	= 0.01 m	
1 meter (m)	= 100 cm	in widespread use throughout all astronomy
1 kilometer (km)	= 1000 m = 10^5 cm	
Earth radius (R_{\oplus})	= 6378 km	planetary astronomy
Solar radius (R_{\odot})	= 6.96×10^8 m	
1 astronomical unit (AU)	= 1.496×10^{11} m	solar system, stellar evolution
1 light-year (ly)	= 9.46×10^{15} m = 63,200 AU	
1 parsec (pc)	= 3.09×10^{16} m = 206,000 AU = 3.26 ly	galactic astronomy, stars and star clusters
1 kiloparsec (kpc)	= 1000 pc	
1 megaparsec (Mpc)	= 1000 kpc	galaxies, galaxy clusters, cosmology
Mass		
1 gram (g)		
1 kilogram (kg)	= 1000 g	in widespread use in many different areas
Earth mass (M_{\oplus})	= 5.98×10^{24} kg	planetary astronomy
Solar mass (M_{\odot})	= 1.99×10^{30} kg	"standard" unit for all mass scales larger than Earth
Time		
1 second (s)		in widespread use throughout astronomy
1 hour (h)	= 3600 s	
1 day (d)	= 86,400 s	planetary and stellar scales
1 year (yr)	= 3.16×10^7 s	virtually all processes occurring on scales larger than a star

Planetary Orbital Data

Planet	Semi-Major Axis		Eccentricity (e)	Perihelion		Aphelion	
	(AU)	(10 ⁶ km)		(AU)	(10 ⁶ km)	(AU)	(10 ⁶ km)
Mercury	0.39	57.9	0.206	0.31	46.0	0.47	69.8
Venus	0.72	108.2	0.007	0.72	107.5	0.73	108.9
Earth	1.00	149.6	0.017	0.98	147.1	1.02	152.1
Mars	1.52	227.9	0.093	1.38	206.6	1.67	249.2
Jupiter	5.20	778.4	0.048	4.95	740.7	5.46	816
Saturn	9.54	1427	0.054	9.02	1349	10.1	1504
Uranus	19.19	2871	0.047	18.3	2736	20.1	3006
Neptune	30.07	4498	0.009	29.8	4460	30.3	4537
Planet	Mean Orbital Speed (km/s)	Sidereal Period (tropical years)	Synodic Period (days)	Inclination to the Ecliptic (degrees)	Greatest Angular Diameter as Seen from Earth (arc seconds)		
Mercury	47.87	0.24	115.88	7.00	13		
Venus	35.02	0.62	583.92	3.39	64		
Earth	29.79	1.00	—	0.01	—		
Mars	24.13	1.88	779.94	1.85	25		
Jupiter	13.06	11.86	398.88	1.31	50		
Saturn	9.65	29.42	378.09	2.49	21		
Uranus	6.80	83.75	369.66	0.77	4.1		
Neptune	5.43	163.7	367.49	1.77	2.4		

Planetary Physical Data

Planet	Equatorial Radius		Mass (kg)	Mean Density (kg/m ³)	Surface Gravity (Earth = 1)	Escape Speed (km/s)	
	(km)	(Earth = 1)					
Mercury	2440	0.38	3.30×10^{23}	5430	0.38	4.2	
Venus	6052	0.95	4.87×10^{24}	5240	0.91	10.4	
Earth	6378	1.00	5.97×10^{24}	5520	1.00	11.2	
Mars	3394	0.53	6.42×10^{23}	3930	0.38	5.0	
Jupiter	71,492	11.21	1.90×10^{27}	1330	2.53	60	
Saturn	60,268	9.45	5.68×10^{26}	690	1.07	36	
Uranus	25,559	4.01	8.68×10^{25}	1270	0.91	21	
Neptune	24,766	3.88	1.02×10^{26}	1640	1.14	24	
Planet	Sidereal Rotation Period (solar days)*	Axial Tilt (degrees)	Surface Magnetic Field (Earth = 1)	Magnetic Axis Tilt (degrees relative to rotation axis)	Albedo [†]	Surface Temperature [‡] (K)	Number of Moons**
Mercury	58.6	0.0	0.011	<10	0.11	100–700	0
Venus	−243.0	177.4	<0.001		0.65	730	0
Earth	0.9973	23.45	1.0	11.5	0.37	290	1
Mars	1.026	23.98	0.001		0.15	180–270	2
Jupiter	0.41	3.08	13.89	9.6	0.52	124	16
Saturn	0.44	26.73	0.67	0.8	0.47	97	26
Uranus	−0.72	97.92	0.74	58.6	0.50	58	27
Neptune	0.67	29.6	0.43	46.0	0.5	59	14

* A negative sign indicates retrograde rotation; [†] Fraction of sunlight reflected from surface; [‡] Temperature is effective temperature for jovian planets; ** Moons more than 10 km in diameter.