How to do reasonably well in SCI 238

Jim Zhang

2019 Jan–Apr

Contents

1 Quick reference

1.1 Values

$$
\begin{aligned}
\text{earth radius} &= 6371\,\text{km} \\
\text{sun radius} &= 6.95 \times 10^5\,\text{km} \\
\text{milky center dist} &= 2.6 \times 10^4\,\text{ly} \\
\text{milky radius} &= 7.5 \times 10^5\,\text{ly} \\
\text{andromeda dist} &= 2.5 \times 10^6\,\text{ly} \\
\text{solar day} &= 24\text{h} \\
\text{sidereal day} &= 23\text{h}56\text{m}4.09\text{s} = 23.93447\text{h} \\
\text{synodic month} &= 29.53\,\text{solar days} \\
\text{sidereal month} &= 27.32\,\text{solar days} \\
\text{tropical year} &= 365.242\,\text{solar days} \\
\text{sidereal year} &= 365.256\,\text{solar days} \\
v_{\text{escape earth}} &= 11.2\,\text{km/s}
\end{aligned}
$$

1.2 Constants

$$
\begin{aligned}
G &= 6.674 \times 10^{-11}\,\text{m}^3/(\text{kg} \cdot \text{s}^2) \\
c &= 2.997 \times 10^8\,\text{m/s} \\
h &= 6.626 \times 10^{-34}\,\text{J} \cdot \text{s} \\
\sigma &= 5.670 \times 10^{-8}\,\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-4} \\
b &= 2.898 \times 10^{-3}\,\text{m} \cdot \text{K}
\end{aligned}
$$

1.3 Unit conversions

$$
\begin{aligned}
1\,\text{eV} &= 1.602 \times 10^{-19}\,\text{J} \\
1\,\text{AU} &= 1.496 \times 10^8\,\text{km} \\
1\,\text{ly} &= 9.461 \times 10^{12}\,\text{km}
\end{aligned}
$$

1.4 Formulas

$$T^2 = \frac{4\pi^2}{G(m_1 + m_2)} a^3 \qquad \text{(Law of periods)}$$

$$F_g = G\frac{m_1 m_2}{d^2} \qquad \text{(Gravity)}$$

$$L = mvr \qquad \text{(Angular momentum)}$$

$$c = \lambda f \qquad \text{(Wavelength-frequency)}$$

$$E = hf \qquad \text{(Photon energy)}$$

$$\frac{v_{\text{rad}}}{c} = \frac{\lambda_{\text{shift}} - \lambda_{\text{rest}}}{\lambda_{\text{rest}}} \qquad \text{(Doppler shift)}$$

$$j^* = \sigma T^4 \qquad \text{(Stefan-Boltzmann law)}$$

$$\lambda_{\max} = b/T \qquad \text{(Wien's displacement law)}$$

$$\alpha = \frac{s}{2\pi d} \times 360^\circ \qquad \text{(Angular separation)}$$

$$\theta = 1.220\frac{\lambda}{D} \times 360^\circ \qquad \text{(Angular resolution)}$$

1.5 Textbook index (6th ed.)

- 92: Math S1.1. P_{orb}, P_{syn}.
- 99: Math S1.2. (local) sidereal time, hour angle.
- 131: Math 4.3. Law of periods.
- 133: Math 4.4. v_{escape}
- 148: Figure 5.7. Electromagnetic spectrum.
- 150: Math 5.1. $c = \lambda f$, $E = hf$.
- 161: Math 5.2. $j^* = \sigma T^4$ (Stefan-Boltzmann law), Wien's law.
- 163: Figure 5.21. Interpreting a spectrum.
- 165: Math 5.3. Doppler shift.
- 175: Math 6.1. Angular resolution.
- 180. Math 6.2. Diffraction limit.
- 185. Figure 6.22. Electromagnetic penetration.
- 200. The solar system and the planet sequence.
- 212. Table 7.1. Planetary data.
- 382. Math 13.1. Exoplanet orbital distance.
- 383. Math 13.2. Exoplanet mass.
- 384. Math 13.3. Exoplanet size.

2 The sky

The **celestial sphere** is a projection of the sky onto a sphere surrounding Earth. The **north celestial pole**, **south celestial pole**, and **celestial equator** are projections of the corresponding things from Earth. The **ecliptic** is the Sun's apparent path in a day. The **analemma** is the position of the sun in the sky at the same mean solar time over the year.

The **local sky** is the half-dome we can see on the surface of the Earth. The **horizon** is the base. The **zenith** is directly overhead. The **meridian** is the north-south half-circle through the zenith. Polar coordinates are **azimuth** (angle clockwise from north) and **altitude** (angle above horizon). **Circumpolar** stars stay above the horizon; they must be near the north celestial pole.

The sky changes through the year. Special moments in the year:

- Spring equinox: March 21
- Summer solstice: June 21 (Cancer)

- Fall equinox: Sep 21
- Winter solstice: Dec 21 (Capricorn)

Tropic of **Capricorn** is 23.5° south; **Cancer** 23.5° north.

The Earth's axis gradually changes due to **precession** with a period of 26,000 years.

2.1 Moon phases

Phase	Rise	Set
New	06:00	18:00
Waxing crescent	09:00	21:00
First quarter	12:00	00:00
Waxing gibbous	15:00	03:00
Full	18:00	06:00
Waning gibbous	21:00	09:00
Third quarter	00:00	12:00
Waning crescent	03:00	15:00

The **Saros cycle** is the 18y11d8h cycle on which eclipses happen. The **Metonic cycle** is the 19 solar years = 235 synodic months coincidence.

The **umbra** is in total shadow; the **penumbra** is partial. An **annular** solar eclipse means the sun isn't fully covered because the moon is too far.

Planets undergo **apparent retrograde motion** when Earth overtakes them in rotation around the sun. **Stellar parallax** is very subtle.

2.2 Precise time

- A **sidereal day** is a full Earth rotation relative to the stars and is 23h56m4.09s. A **solar day** is 24h and is based on the apparent position of the sun.
- A **sidereal month** is a full moon revolution around the Earth and is 27d8h. A **synodic month** is the time between new moons and is 29d12h.
- A **sidereal year** is a full Earth revolution around the sun. A **tropical year** is the time between March equinoxes. These are different because of precession.
- A planet's **sidereal period** is an orbit relative to the stars. A planet's **synodic period** is the time between alignments in our sky.
- A **conjunction** is being lined up with the sun; an **opposition** is being opposite of the sun. Planets closer to the sun than Earth don't have oppositions, but they do have an **inferior conjunction** (close) and **superior conjunction** (far). **Greatest elongation** is when an inner planet is farthest from the sun in the sky. A **transit** is a tiny little solar eclipse.
- **Apparent solar time** is based on sun's actual location. **Mean solar time** is averaged over the whole year.
- **Standard time** is the system of time zones. **Universal time** (UTC) is GMT.
- The Egyptian calendar sucked. The **Julian calendar** added leap years every 4 years. The **Gregorian calendar** removed leap years every 100 years and put them back every 400 years to keep the equinoxes real consistent.

2.3 Celestial coordinates

They're global sky coordinates. **Declination** (dec) is latitude (away from celestial equator), and **right ascension** (RA) is longitude (away from the March equinox). At a latitude of lat, the celestial equator crosses the meridian at an altitude of $90 - lat$.

3 History

- **Thales** (600 BC) got rid of magic and predicted a solar eclipse.
- **Anaximander** (590 BC) did the celestial sphere (but he thought Earth was a cylinder)
- **Pythagoras** (540 BC) said Earth is a sphere because spheres are perfect.
- **Anaxagoras** (480 BC) said that the Earth and sky are made up of the same stuff.
- **Democritus** (450 BC) did atoms.
- **Meton** (430 BC) found the Metonic cycle.
- **Plato** (410 BC) said that things move in circles.
- **Eudoxus** (380 BC) said that Plato's spheres are nested.
- **Aristotle** (360 BC) argued that Earth is the center.
- **Heracleides** (360 BC) said Earth rotates.
- **Aristarchus** (290 BC) said Earth goes around the sun.
- **Eratosthenes** (260 BC) accurately estimated Earth circumference.
- **Apollonius** (220 BC) did epicycles.
- **Hipparchus** (170 BC) did precession, log star brightness
- **Ptolemy** (120 AD) made his model so it gets his name.
- **Copernicus** (1473–1543) made a **heliocentric model**.

- **Tycho Brahe** (1546–1601) provided data via naked-eye observations.
- **Kepler** (1571–1630) did ellipses. Kepler's laws are:
  1. The orbit of a planet is an ellipse with the sun at one focus.
  2. A planet moves faster near the sun, sweeping out area at a constant rate.
  3. $p^2 = a^3$, where p is orbital period (years) and a is average distance (AU)
- **Galileo** (1564–1642) used a telescope and solidified heliocentrism by answering the three objections (Newton's first law, circular perfection, stellar parallax).

3.1 Orbits in detail

The **eccentricity** of an ellipse is the focal distance over the major diameter.

The average orbital radius is equal to the length of the semimajor axis.

The **aphelion** is the farthest point, and the **perihelion** is the closest point, in an orbit from a sun. The **apogee** and **perigee** are the same, but for orbits around the Earth.

The orbital speed $\propto 1/$ the orbital radius.

4 Physics

Newton (1642-1727) did gravity and said it's the same in the heavens as on Earth. His three laws:

1. Zero net force means velocity stays the same
2. $F = ma = dp/dt$
3. All forces have an equal opposite force.

Conservation of momentum/angular momentum/energy: They're all constant in a closed system.

Types of energy: kinetic (thermal), radiative, potential (gravitational, chemical)

Newton found **unbound orbits**: when objects never come back. All orbits are conic sections.

Orbital energy (kinetic and gravitational potential energy of an orbiter) stays constant.

A **gravitational encounter** is when two things pass "close enough" to "feel" each other's gravity.

Tides happen because the moon's gravity is stronger on the near side than the far side. High **spring tides** happen at new and full moon when the sun and moon's gravity align; **neap tides** are the opposite. **Tidal friction**: The tidal bulges actually lead the moon by a bit due to Earth's rotation. This also slows Earth's rotation (a second is gained about every 50,000 years). This also explains the moon's **synchronous rotation**.

5 Light and matter

Ways light interacts with matter: **emission**, **absorption**, **transmission** (letting it go through), and **reflection/scattering**.

5.1 Phase changes

In water: **solid**, **liquid**, **gas**, **molecular dissociation** (molecules break apart at thousands of K), **plasma** (free elections bounce around at tens of thousands of K), **fully ionized plasma** (at millions of K)

5.2 Spectra

A **continuous spectrum** contains basically all wavelengths and is emitted by incandescent light.

An **emission line spectrum** contains only a few bright lines and is emitted by low-density clouds of gas.

An **absorption line spectrum** contains a few notches that indicate that certain wavelengths are being absorbed.

For a particular gas, its emission lines correspond exactly to its absorption lines because quantum.

The ionization state of an atom affects its lines. Molecules also produce spectral fingerprints with tightly bunched lines called **molecular bands**.

Thermal radiation/blackbody radiation is emitted by hot things in distinctive spectra governed by two laws:

1. **Stefan-Boltzmann law**: Hotter things emit more light at all wavelengths.
2. **Wien's law**: Hotter things emit photons with a higher average energy.

The **Doppler effect** shifts wavelengths and lines allowing us to determine how fast things are moving away from us (as well as their rotation speed!).

6 Telescopes

An **image** is formed when light is brought to a **focus**, with images at the **focal plane** the clearest.

6.1 About telescopes

Properties of telescopes that matter:

- **Light-collecting area**: The bigger, the better
- **Angular resolution**: Smallest angle it can tell apart two dots. Our eyes have a resolution of about 1 arcminute.

The **diffraction limit** is the best possible angular resolution if limited only by light wave interference. It's larger the longer the wavelength.

A **refracting** telescope uses lenses; a **reflecting** telescope uses mirrors. Most astronomical telescopes are reflectors because it reduces the need for clear glass and only the surface of the mirror (rather than an entire lens) must be precisely shaped. Lenses also introduce **chromatic aberration** (different refraction of different wavelengths).

Three types of reflecting telescope:

- **Cassegrain focus**: Mirror reflects to mirror2 focuses through first mirror.
- **Newtonian focus**: Mirror reflects to mirror2 focuses off to the side.
- **Nasmyth/Coudé focus**: Mirror reflects to mirror2 reflects to mirror3 focuses off to the side.

Spectrographs separate colors using a **diffraction grating** (sometimes). **Spectral resolution** is a thing. **Light curves** show brightness over time.

6.2 Effects of the atmosphere

Light pollution is when city light scatters back to the Earth.

Atmospheric blurring is when air turbulence bends light, causing the sky to shift around. It limits ground-based angular resolution to 0.5 arcseconds, unless you use **adaptive optics** which fixes it computationally.

Good viewing sites are **dark**, **dry**, **calm** and **high**.

6.3 Telescope instances

- **Radio telescopes** like satellite dishes. Must be big for reasonable resolution, e.g. Arecibo is 305 meters across and has 1 arcminute of resolution.
- **Infrared telescopes** are similar to visible light telescopes.
- **Ultraviolet telescopes** are also similar to visible light telescopes, but must be in space.
- **X-ray telescopes** must be in space and use special **grazing incidence mirrors** so that the mirrors themselves aren't damaged.
- **Gamma ray telescopes** cannot be focused; instead, special detectors are used.

Neutrinos, **cosmic rays** (nuclei), and **gravitational waves** are also things.

You can use multiple telescopes to capture a single super high resolution image using **interferometry**. (e.g. Very Large Array)

7 The solar system

Comparative planetology is studying planets/moons/asteroids/comets in relation to each other.

Planets can be **rocky** or **jovian**.

Asteroids and comets are concentrated in three regions: the **asteroid belt** between Mars and Jupiter, the **Kuiper belt** beyond Neptune, and the **Oort cloud**, a sphere of asteroids quite far away.

7.1 Things in it

7.1.1 The Sun

Radius: 108 Earth radiuses = 696000 km

Mass: 333,000 Earth masses

Composition: 98% H, He; 2% other

The surface is 5800K hot. Sunspots are cooler than their surroundings. Every second, the sun burns 600 million tons of H into 596 million tons of He. The sun also expels **solar wind**, mostly electrons and protons.

7.1.2 Mercury

Days and nights last about 3 months each because tides have screwed up Mercury's rotation pattern.

7.1.3 Venus

Rotates in the opposite direction of Earth. The **greenhouse effect** makes Venus super hot.

7.1.4 Earth's

Moderate greenhouse effect due to CO_2 and water vapor.

7.1.5 Mars

Moons: 2 (very small): Phobos, Deimos

7.1.6 Jupiter

Has no solid surface; we would fall in and be crushed by the pressure. The Great Red Spot is 2-3 times the size of Earth. Four moons are big (they would qualify as (dwarf) planets): Io, Europa, Ganymede, and Callisto. Io is extreme volcano boy. Europa is icy boy, possibly with water underneath.

7.1.7 Saturn

Has the most visible rings. Big moons include Enceladus and Titan. Titan has riverbeds and lakes — of (m)ethane.

7.1.8 Uranus

Days are the same as years, and are 84 Earth years long become the axis is tilted on its side.

7.1.9 Neptune

Triton orbits backwards. Conclusion: Triton probably once orbited the Sun independently.

7.1.10 Pluto

Not a planet, is a dwarf planet.

7.2 Patterns

Four major patterns:

1. The orbits and rotations of big things are organized.
2. Two types of planets: terrestrial and jovian.
3. Asteroids and comets exist.
4. Exceptions exist.

7.3 Missions

1. **Flyby**: Fly past a thing. Cheap, efficient, can use gravitational slingshot.
2. **Orbiter**: Orbit a thing. Can brake using the atmosphere (called aerobraking).
3. **Lander/probe**: Land on a thing, or travel through its atmosphere.
4. **Sample return**: Bring stuff from the thing back to Earth.

8 Planetary geology (Ch9)

Four ways planet surface are shaped: impact cratering, volcanism, tectonics, erosion. **Hot jupiters** formed farther away then migrated inward.

9 Other planetary systems (Ch13)

Direct detection is finding an exoplanet by taking a picture of it. It's really hard. Most of what we know about extrasolar planets comes from indirect approaches.

The **astrometric method** uses very precise measurements of the positions of stars. Not that great for smaller planets (relative to the star). Two limitations:

1. Need a crapton of angular resolution, so best for small stars
2. Works better if planet orbits star farther away because the centre of mass is farther — but this increases time span of observations needed

The **Doppler method** observes changes in the Doppler shift over time. Three limitations:

1. Same as above
2. Best when planets orbit close to the star, due to stronger gravitational tug
3. Requires a big telescope and long exposure time

The **transit method** is monitoring the star's brightness over time. It gets darker when there's a transit or (to a lesser extent) an eclipse. Advantages are:

1. Can find much smaller planets than motion methods
2. Can distinguish easily between multiple planets

9.1 Properties we can measure

	Planetary Property	Method(s) Used	Explanation
Orbital Properties	**period**	Doppler, astrometric, or transit	We directly measure orbital period.
	distance	Doppler, astrometric, or transit	We calculate orbital distance from orbital period using Newton's version of Kepler's third law (Mathematical Insight 13.1).
	eccentricity	Doppler or astrometric	Velocity curves and astrometric star positions reveal eccentricity (Figure 13.7).
	inclination	transit or astrometric	Transits identify edge-on orbits; astrometric data measure any inclination angle.
Physical Properties	**mass**	astrometric or Doppler*	We calculate mass based on the amount of stellar motion caused by the planet's gravitational tug (Mathematical Insight 13.2).
	size (radius)	transit	We calculate size based on the amount of dip in a star's brightness during a transit (Mathematical Insight 13.3).
	density	transit and Doppler	We calculate density by dividing the mass by the volume (using size from transit method). See Figure 13.10.
	atmospheric composition and temperature	transit or direct detection	Transits and eclipses provide data on atmospheric composition and temperature.