

1 Earth and Moon

- Read chapter 7 in the textbook
- Exercises: Do all “Review and Discussion” and all “Conceptual Self-Test”

2 Earth: the best known planet

2.1 The Earth’s Atmosphere

- Mixture of gases: N₂ (78%), O₂ (21%), Ar (0.9%), CO₂ (0.03%)
- considerable amount of water vapour (0.1% – 3%)
- SEE Figure 7.2
- atmospheric structure – layers
- **troposphere**
 - surface up to about 12km
 - region of the atmosphere with weather
 - highest pressure part of the atmosphere – breathable
 - lower regions warmest
- **stratosphere**
 - just above the troposphere
 - extends to about 50km
 - warms up with altitude – UV absorption
 - little weather – airlines fly here
- **Mesosphere**
 - 50km to about 85km
 - temperature decreases with height
 - meteors burn up here
- **thermosphere (ionosphere)**
 - 90km to about 700km
 - partly ionized gases from solar radiation
 - temperature begins to increase again from solar radiation effects

- reflective to radio waves of certain lengths (AM radio)
- auroras (northern/southern lights) occur here
- Exosphere above the thermosphere
- atmospheric ozone – stratosphere, ozone layer
- ozone layer, altitude 25km
- ozone O₃ – unstable molecule
- UV radiation: O₃ → O₂
- Ozone “absorbs” the UV radiation – shields earth
- CFCs contain a chlorine atom that acts as a catalyst in destroying ozone
- CFCs have reduced atmospheric ozone worldwide – massive deficit (50%) discovered over Antarctic in the 1980s; up to 20% in mid-latitudes
- international agreement to phase out CFCs – phase out by 2030
- CFCs will continue to destroy ozone for decades
- SEE Figure 7.4
- sky appears blue – atmospheric scatterers
- molecules scatters $\propto 1/\text{wavelength}^4$
- dust scatters $\propto 1/\text{wavelength}$
- SEE MP 7.1
- weather – convection, uneven heating of the earth’s surface and atmosphere
- convection – warm air expands, becomes less dense, “floats upward”, cools, sink
- SEE Figure 7.3
- Earth does not absorb all sunlight – reflects about 36% back into space, albedo
- most of the light that reaches the Earth’s surface – visible light and near infrared
- Earth balances the radiation it receives by re-emitting back into space
- without any complications – surface temperature -23°C
- atmosphere complicates the picture – holds on to the heat like a blanket
- water vapour and carbon dioxide excellent infrared absorbers

- water vapour and carbon dioxide – small amounts in the atmosphere still large effect – greenhouse effect
- greenhouse effect moves temperature up from -23°C to 15°C – important for life!
- temperature on earth governed by atmosphere, axis tilt, and finally distance – complicated picture
- greenhouse effect sensitive to the amount of greenhouse gases
- SEE Figure 7.5
- carbon dioxide increasing in the atmosphere – human activity
- serious problem for the 21st century
- extremes of atmospheric evolution – runaway greenhouse effect (Venus), atmospheric depletion (Mars)
- origin of the earth’s atmosphere – not always like it is today
- Earth’s history – primary atmosphere, hydrogen, helium, methane, ammonia, water vapour
- low density gases escaped over the first 500 million years
- secondary atmosphere – outgassing from planets interior, volcanic activity: water vapour, methane, carbon dioxide, sulphur dioxide, and nitrogen compounds
- solar radiation broke compounds down, liberating nitrogen
- Earth’s surface cooler, water vapour condensed out, oceans formed
- carbon dioxide, sulphur dioxide dissolved in oceans and surface rocks
- oxygen largely absent – comes later with life in the oceans
- oxygen atmosphere direct consequence of evolution of life

2.2 Earth’s interior and surface

- main regions of the Earth: inner core, outer core, mantle, crust
- SEE Figure 7.1
- cannot probe the Earth’s interior directly – cannot drill below 10km
- modelling interior – earthquakes!
- earthquakes – seismic waves

- seismic wave two types: P-waves and S-waves
- P-waves (pressure waves) vibrate in the direction of travel – compression waves
- S-waves (shear waves) vibrate perpendicular to travel
- SEE Figure 7.6
- P-waves (5-6km/s), S-waves (3-4km/s)
- P-waves can travel through liquid, S-waves cannot
- can use P and S waves to obtain information on the Earth's interior
- earthquakes cause the Earth to ring like a bell
- seismic stations: never observe S-waves directly opposite the earthquake – S-wave shadow
- P-waves also show shadow regions
- P-wave shadows: refraction-like effect
- S-wave shadow: liquid outer core
- size of the shadow regions reveal size of core (3500km)
- reveals core structure: inner and outer core
- SEE figure 7.7
- interior modelled
 - outer core surrounded by thick mantle
 - mantle 3000km thick – 80% of planets volume, dense, rocky material (silicon and oxygen)
 - basalt denser than granite – granite floats atop denser material below
 - upper mantle – probably basalt (iron, magnesium, silicate)
 - crust 16km thick (3gm/cm³)
 - density and temperature increase with depth 3gm/cm³) – 12gm/cm³); 300 K – 5000K
 - core – iron, nickel
 - outer core, liquid inner core solid from high pressure
 - SEE Figure 7.8 and Discovery 7-2
- Differentiated picture emerges - not solid homogeneous rock

- early history - earth capturing material, sweeping up debris
- generated a lot of heat – earth molten
- denser material sank increasing core temperature further
- natural occurring radioactivity generated more heat
- MP 7.2
- rock, good insulator
- crust began to solidify 700 million years after planet formed
- cooling ever since from the outside in
- Earth still an active place
- mid-1960s – realized that regions of geological activity delineated giant plates
- plate dynamics – plate tectonics (original idea continental drift)
- original idea 1912 Alfred Wegener – coastline fit (not taken too seriously at the time)
- SEE Figure 7.11
- plates taken together – lithosphere, sits on top of plastic asthenosphere
- plates driven by convective effect in the upper mantle/asthenosphere – rigid lithosphere (granite) floats above
- plates slide into one another and past one another – upward building features (mountains), earthquakes
- SEE Figure 7.13 and 7.14
- divergent boundaries (plates moving apart) and subduction zones (plates sliding under one another)
- divergent boundaries – ocean ridges; subduction zones – ocean trenches
- SEE Figure 7.12 and 7.15
- plates move a couple of cm per year
- effect can be observed with radio astronomy!
- Mid-Atlantic Ridge – divergent boundary, Atlantic ocean growing
- new material emerging – volcanism (Iceland)

- emerging material contains some iron, imprints the Earth's magnetic field as material cools
- studies reveal Earth's magnetic field reverses polarity approx every 500,000 years
- subduction zones/divergent boundaries – rock cycle
- rock cycle, redistributes and transforms surface rock on the planet
- igneous rock, sedimentary rock, metamorphic rock
- past continental drift – continents all pushed together 200 million years ago
- Pangaea – super continent
- SEE Figure 7.18
- fossils record also indicates this
- several Pangaeas in Earth's history – driven together by tectonic forces
- continual process – more Pangaeas in the future
- Earth's dynamics – more than just plate tectonics – Magnetosphere
- dynamo theory – rotation and conducting liquid outer core – creates/maintains Earth's magnetic field
- we will see the dynamo theory at work throughout the solar system
- Earth's magnetic field interacts with the solar wind (charged particles from the sun)
- magnetic field sets up Van Allen radiation belts – trapped charged particles
- SEE Figure 7.19 and 7.20
- charge particles can leak out of the Van Allen belts near the poles – particles interact with the upper atmosphere Northern/Southern Lights (Aurora)
- in addition to internal processes – gravitational influences
- largest effect moon and sun
- gravity – diminish with distance
- moon (sun) creates tidal bulge on the earth – slightly distorts the earth
- tidal bulge – differential gravitational force
- sun-moon effect – spring tide and neap tide

- SEE Figure 7.22 and 7.23
- tidal friction – slows the Earth’s rotation – bulge wants to line up with the moon
- Earth moon system – eventually tidally locked (like the moon is now)
- Earth’s rotation – 47 days, moon 550,000km away (will take many billions of years)

3 The Moon

- size and distance known since antiquity
- Physical parameters: SEE Table 1
- Mass, 7.35×10^{22} kg (about 1/80 mass of the earth)
- average density 3.3gm/cm^3 – substantially less than the Earth
- gravitational field much weaker than earth (0.17 of Earth’s)
- no atmosphere on the moon (trace amounts of Argon)
- reason for an atmosphere: read MP 8-1
- no atmosphere, wide temperature swings (400 K at noon, 100K at night)
- one face always points toward the Earth – tidally locked
- Galileo, first to observe lunar surface with a telescope, recognized relief
- dark areas, thought to be oceans, seas (maria, from Latin) – give man in the moon appearance
- 14 maria, roughly circular in shape
- lighter area, (terrae, from Latin for land), elevated above the maria – lunar highlands
- Apollo 11, Sea of Tranquility
- human eye, 200km across on the moon
- telescopes (best down to 1km), see craters
- craters everywhere on the moon’s surface
- maria are not seas – solidified lava (basalt), early volcanism
- almost all of the maria appear on the nearside
- not caused by Earth’s gravitational field – perhaps thinner crust

- meteoroids – primary agent of change on lunar surface
- on Earth – meteors (shooting stars) burn up
- impact on the moon – several km/s
- 1kg at 10 km/s – 10kg TNT
- constant rain of micrometeoroids – covers surface features (20 m deep crater deficit)
- pulverized ejecta, dust, covers surface 10m – 100m (regolith)
- maria solidified after the highlands – difference in cratering
- current rate 10 km every 10 million years, 1 metre every month
- erosion rate, slow – 5 m per billion years
- erosion rate much faster on earth
- moon instrumental in helping to understand the ages of other bodies
- cratering on other bodies compared to moon, determine age
- radioactive dating with Apollo mission rocks, 4.6 billion years
- moon's interior similar to Earth's Mantle
- inner core maybe partially molten
- geologically quiet – no present day volcanism, no plate tectonics
- moon's crust thicker than earth's – cooled faster
- crust thicker on the farside – perhaps earth's influence
- core, 300km, soft asthenosphere 400km above core
- no magnetic field – core different from earth
- history of lunar volcanism – rilles, collapse domes
- lunar prospector – possible discovery of lunar ice
- theories of origin: co-formation, fission, impact
- impact theory most accepted – Earth collision with Mars sized object
- Earth partially differentiated at time of collision
- iron core of Earth and object remains with Earth – mantle material ends up with moon
- computer simulations show support for this model – questions still remain