The Giant Planets

- Huge : radii 5-10 times that of Earth

  Masses 15 (Uranus) to 318 (Jupiter) times Earth's

- Mean density ~ 1

- Each has a large number of ~~sattel~~ satellites

  Each also has rings, although their properties differ.

- Compositions are more like the Sun's than like Earth's:

  mainly H and He.

- We think (but have no direct proof) that the giant planets also have a denser (rocky?) central core

- Giant planets have no surface such as terrestrial planets: atmospheres just get thicker
- Only outer atmospheres can be observed directly, even with space probes

Q Why do we not know definitely about the giant planets' rocky cores ?

JUPITER

- 318 times mass of Earth
  (0.1% of $M_\odot$)
  Total of rest of planets is only 129 Earth masses
  Most of angular momentum in solar system
  carried by Jupiter

- accel^n due to gravity at cloud tops ~2.5g
  composition 99% light gases < 75% H, 24% He by mass
  - Mean density 1.24 g/cm^3
  - different colors of clouds from chemistry
    NH_3, NH_4SH, H_2O

- rapid rotation 9.9h @ equator, differential
  ⇒ strong winds < zones light, belts dark

  great red spot

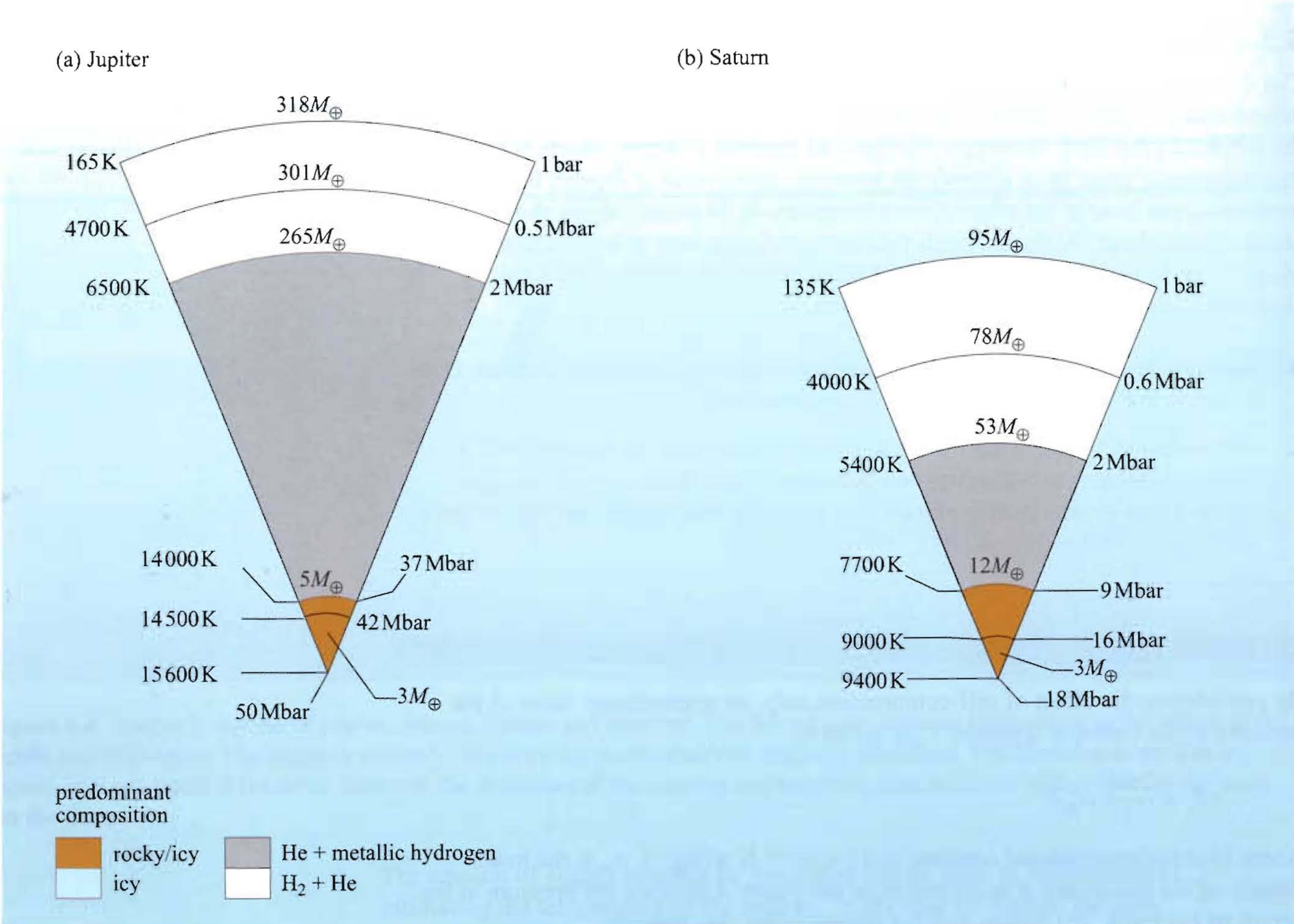

Figure 6.5 Cross-sections through (a) Jupiter and (b) Saturn.

metallic, read Box 6.2.

BOX 6.2 METALLIC BONDING

A simple picture of a metal such as aluminium, familiar to us on Earth, is of an orderly set of positively charged ions surrounded by electrons, which are shared. Imagine some aluminium ions arranged as in Figure 6.6.

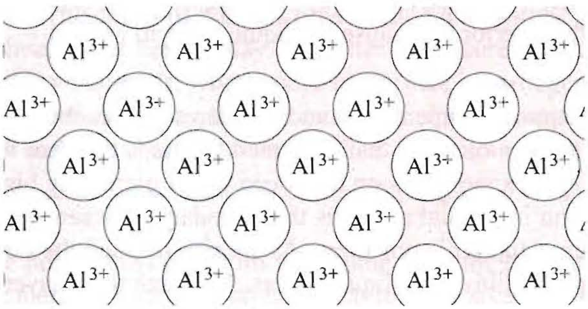

Figure 6.6 Aluminium ions (Al^{3+}) arranged as though in a crystal of aluminium. The electrons 'lost' from the atoms wander freely through the solid.

Now, the most common ion formed by aluminium is Al^{3+}, in which the aluminium atom has lost three electrons. Suppose the lost electrons are allowed to wander freely about the crystal. You may recall that two atoms can form a chemical bond by sharing electrons. In our picture of aluminium, the freely wandering electrons are shared by all the ions in the crystal, and thus serve to bond together all the ions. This sharing of electrons by a whole crystal constitutes **metallic bonding**. The electrons are responsible for many of the characteristic metallic properties of elements such as aluminium. In particular, they can move through the solid and, because they are electrons, they carry negative electrical charge with them. A moving electrical charge is an electric current, and so metallic bonding leads to electrical conductivity.

- Aluminium is a solid at everyday temperatures and pressures, but there is one common liquid metal found at the Earth's surface. What is it?
- Mercury (Hg). You may have a mercury thermometer or barometer at home.

In liquid mercury, the situation is similar to that shown in Figure 6.6 except that because mercury (Hg) is a liquid, the ions are not so ordered (Figure 6.7).

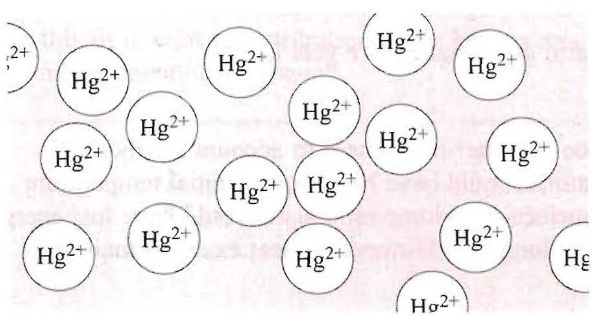

Figure 6.7 Mercury ions (Hg^{2+}) arranged as though in liquid mercury. The 'lost' electrons are free to travel through the liquid, but the arrangement of the ions is less regular than in solid aluminium.

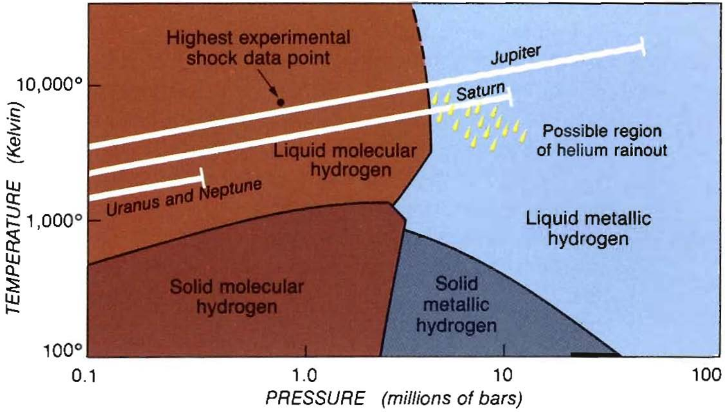

Figure 5. A phase diagram for hydrogen, showing the domains of liquid metallic and molecular hydrogen (the main components in Jupiter and Saturn), as well as approximate interior temperature profiles for the Jovian planets. Color shading indicates where helium "rain-out" may occur, a zone where a solar-composition mixture of metallic hydrogen and helium cannot exist in equilibrium.

INSIDE JUPITER

As we move down from the cloud tops,
it gets warmer & denser & pressure increases
(Like the Sun, hydrostatic equilibrium
holds it up)

- At the cloudtops, pressure half of Earth's atmosphere, Temperature 125 K (almost -300F)

- As you move in, warmer & higher pressure (atmosphere thickens)

- 1/3 of way in, planet is made of a silvery liquid which looks like quicksilver — metallic Hydrogen

- almost at the center:

  temperature 20,000° K

  pressure 10^7 times Earth's atmosphere

  (the Sun is much hotter : 10^7 °K at center)

  ~ 1000 times –

  Jupiter's central temperature and pressure are not high enough for nuclear fusion

- at the center (we think)

  a small, rocky core, about 10 Earth masses

INTERIOR

at cloud tops, temp 125 K, pressure ½ atm.

brown clouds	200 K	1 atm
250 km down	1000 K	> 100 atm
1500 km down	3000 K	10,000 atm
⋮		
21,000 km down		$> 10^6$ atm

* liquid metallic H *

⋮

~ 70,000 km down	20,000 K (center)	10^7 atm

* small rocky core *

model constraints
- pressurize H_2
- solid-state physics

Q How are phase diagrams constructed?

- theoretically?
- experimentally?

Temperature at cloud tops (what we see, remember H & He gas are transparent) is 125 K (−300F!)

Increases as we go inward, reaches about 10,000 K (10^4 K) at center, where pressure is enormous (over 1 million atmospheres)

but not as hot as Sun's center (10^7 K) or as high in pressure (10^9 atm)

Very different physical states produced

Q Jupiter doesnt have a molten Fe core like the Earth's, but it does have a region where the hydrogen is under so much pressure it is liquid.

Would you expect Jupiter to have a magnetic field? Why?

A Jupiter does have a strong magnetic field, caused (like the Earth's) by a dynamo effect. In Jupiter's case the moving charges are in the metallic hydrogen.

OUTER PLANETS

Saturn – second largest planet (94 Earth masses)

– low density ~ 0.7 gm/cm^3

– 10h 39m day

– like a cooler Jupiter – similar clouds, atmospheric effects

– ~ 90 K near top of atmosphere

Uranus & Neptune

Twins, almost : ~5% Jupiter mass

Both ~ 60 K near top of atmosphere

Uranus spin – tilted 98° to ecliptic

Dark blue-green in color – methane in atmosphere absorbs red light

Gas giant seismology

While the gas giants are not solids which allow seismological studies of the interior (like the Earth) we can use a ~~similar~~ related technique.

Planets (and stars) undergo global oscillations which are non-radial.

(Stars can also pulsate : a radial oscillation where they become larger & then smaller but stay ~ spherical)

There are also many possible non-radial oscillations where the shape changes periodically as the star or giant planet deforms

In the same way the sound of a bell depends on its composition, the structure and composition of the giant planet determines the way it oscillates. Including the core! (→ sound speed)

Astronomers measure these oscillations either via measuring the velocity of different parts of the surface as they move in & out, or by measuring changes in brightness during oscillations.

This is a mature field in the study of the Sun's structure ("helioseismology") with a network of telescopes worldwide to monitor the oscillations.

It is a much newer field in the study of the giant planets, but oscillations of Jupiter were detected in the mid 90's.

Technique is very powerful: important confirmation of theories of solar structure already.

Q Why do you think this is more challenging for the giant planets than for the Sun? Give several reasons.

A Giant planets are much fainter than the Sun.

They have weather which will add noise to the oscillation signal.

Their moons can also deform them tidally.