Self-assessment questions for *An Introduction to the Solar System*

Question 1

For detail to the following answers refer to Sections 1.1.2, 2.5.4, 3.3.3 and 3.4.4 and Appendix A (p.376)

(a) Any lander design will have to contend with ensuring the safe deliverance of the instrument package to the surface; this would require slowing/braking of the package's descent through the atmosphere.
The composition of the upper atmosphere is highly corrosive and passage through the clouds of Venus's atmosphere would allow exposure to these, so the lander package would need to be resistant to droplets of sulfuric acid.
Instruments would also require protection from impact with an uneven and rocky surface.
Once delivered, the package would need to withstand the high pressures (c. 92.1 bar, OR more than 90 times the pressure experienced on Earth;
The instrumentation would also need to withstand the high temperatures c. 733 K or 460 °C (allow 670 K OR 400 °C;) that characterize the conditions on the surface of Venus.

(b) *A good answer would include most of the following*
There would be an absence of any water (surface conditions are too hot), so the surface would be rock.
Since there is no water, there would be no life.
The surface is too hot for aqueous chemistry, so aqueous corrosion is unlikely (i.e. 'rusting').
However, the action of components in the atmosphere has are likely to have given rise to some degree of weathering/alteration, whilst wind action will have caused some erosion.
Therefore, some sediment or regolith may be discernable as well as rock fragments, for instance, as seen on Venera lander images (e.g. *An Introduction to the Solar System*, Figure 1.7).
The surface of Venus is characterized by numerous major, and innumerable small volcanoes, so it is possible that part of one or more of these would be in view. The surface is also predominantly covered by extensive lava flows, and there may be a covering of pyroclastic material.
The relatively young surface (500 Ma) means there are likely to be fewer impact craters (than compared with the Moon or Mercury), whilst a thick atmosphere would have prevented smaller meteorites reaching the surface so there are likely to be few small impact craters.
However, depending on the landing site, a larger impact basin may be present.
Due to the thick atmosphere, the Sun may not be visible, and the surface would be illuminated with a diffused light.

Question 2

(a) The most common eruptive product on Earth is basalt – more specifically mid-ocean ridge basalt – MORB which covers 70% of the Earth's surface (komatiite is no longer a significant eruptive product on Earth) (*An Introduction to the Solar System*, Section 3.4.1)
A large fraction of Io's Fe-Mg rich upper mantle may be molten. If correct, the most common eruptive product on Io is likely to be komatiite (a type of basalt) (*An Introduction to the Solar System*, Section 3.4.6). Thermal images of some of the erupting lava flows on Io's surface indicate very high eruption temperatures which would support this interpretation.

(b) Primordial heat includes:
That derived from the collision and accretion of planetary embryos during planetary assembly and, after the planet had assembled, that delivered to the surface by impact events through bombardment by incoming debris.
Impact heating occurs as a consequence of the conversion of gravitational potential energy to kinetic energy, and then to heat during an impact event.

Primordial heat also includes heat released by the gravitational separation of denser components within the planet, for instance during core formation.
Core formation involves a conversion of gravitational potential energy, to kinetic energy, and then to heat, as the material sinks inward during the separation event. (p.61-62, 82.)

(c) The two processes responsible for long-term internal heating of terrestrial-like bodies are radiogenic and tidal heating (as given in Table 1), these may be described as follows (*An Introduction to the Solar System*, p.62 – 65, 80, 82.):-
Radiogenic heating is the result of natural decay of radioactive elements (e.g. ^{235}U, ^{238}U, ^{232}Th and ^{40}K).
These radiogenic elements occur in the silicate-rich mantle and crustal layers. The amount of radioactive decay and hence heating decreases over time because there were considerably more radioactive elements present earlier in the history (i.e. juvenile stages) of planetary evolution.
This radiogenic heat would have been augmented by the decay of short-lived isotopes such as ^{26}Al in these early stages.

Tidal effects are generated by the distortion of shape (tidal bulges) of the bodies as a result of mutual gravitational attraction.
However, since these tidal effects cause slowing of rotation, the amount of tidal heating will diminish through time, but remains significant (the reasons for this are not described in *An Introduction to the Solar System*) in some satellites of the giant planets.

(d) a) Completed Table 1: Values for total heat production in Io are provided in *An Introduction to the Solar System*, Section 2.5.6 (p.80).

Table 1 - completed.

Current global heat production in Io and the Earth

	Tidal heat production / W	**Radiogenic heat production / W**
Io	4×10^{13}	5×10^{11}
Earth	9×10^{11}	3×10^{13}

Values for radiogenic and tidal heat production in Earth are given as a flux per kg (i.e. 5×10^{-12} W kg^{-1} and 'about 1/30th' which is 1.5×10^{-13} W kg^{-1} – in *An Introduction to the Solar System*, Section 2.4.3, p.66). To complete Table 1, you need to determine the total heating internally generated within the Earth in both cases. The mass of the Earth is given in Appendix A as 5.97×10^{24} kg. Hence:

Earth's radiogenic heat production is:

5×10^{-12} W kg^{-1} $\times 5.97 \times 10^{24}$ kg $= 2.98 \times 10^{13}$ W $= 3 \times 10^{13}$ W

Earth's tidal heat production is:

1.5×10^{-13} W kg^{-1} $\times 5.97 \times 10^{24}$ kg $= 8.96 \times 10^{11}$ W $= 9 \times 10^{11}$ W

Alternative method to above:

An Introduction to the Solar System, Q2.6 gives Earth's tidal heat production as 3.0×10^{19} J yr^{-1}

Therefore, since are $(365 \times 24 \times 60 \times 60) = 3.16 \times 10^{7}$ seconds in a year:

Earth's tidal heat production is:

$(3.0 \times 10^{19}$ J yr$^{-1}) / (3.16 \times 10^{7}$ s yr$^{-1}) = 0.949 \times 10^{12}$ J s^{-1} $= 9 \times 10^{11}$ W

For Io, tidal heat production is about 80 times greater than radiogenic heat production

For Earth, radiogenic heat production is about 30 times greater than tidal heat production

(e) Using the calculation outlined in Box 2.8 (*An Introduction to the Solar System*, p. 66), and the radius dimensions of Earth and Io dimensions given in Appendix A (*An Introduction to the Solar System*, p. 376):

Sphere volume = $4/3\ \pi r^3$

Sphere surface area = $4\pi r^2$

Earth volume = $4\pi(6371000)^2 = 1.0832 \times 10^{21}\ m^2$

Earth surface area = $4/3\ \pi(6371000)^3 = 5.1006 \times 10^{14}\ m^3$

Earth Surface area/ volume ratio

= $5.1006 \times 10^{14}/1.0832 \times 10^{21} = 4.7088 \times 10^{-7}$

= 4.709×10^{-7} (to four sig. figs)

Io volume = $4\pi(1821000)^2 = 2.5294 \times 10^{19}\ m^2$

Io surface area = $4/3\ \pi(1821000)^3 = 4.1671 \times 10^{13}\ m^3$

Io Surface area/ volume ratio

= $4.1671 \times 10^{13}/2.5294 \times 10^{19} = 1.6474 \times 10^{-6}$

= 1.647×10^{-6} (to four sig. figs)

Io is likely to lose its internal heat most efficiently because its surface area to volume ratio is c. 3.5 times greater than that of the Earth.

Alternative approach to 2(e):

Surface area of a sphere of radius R = $4\pi R^2$

Volume of a sphere of radius R = $^4/_3\pi R^3$

So:

Earth surface area = $4\pi \times (6371\text{ km})^2 = 5.101 \times 10^8\text{ km}^2$

Earth volume = $^4/_3\pi \times (6371\text{ km})^3 = 1.083 \times 10^{12}\text{ km}^3$

Earth surface area/ volume ratio

$= (5.101 \times 10^8\text{ km}^2) / (1.083 \times 10^{12}\text{ km}^3)$

$= 4.709 \times 10^{-4}\text{ km}^{-1}$ (to 4 sig. figs)

Io surface area = $4\pi \times (1821\text{ km})^2 = 4.167 \times 10^7\text{ km}^2$

Io volume = $^4/_3\pi \times (1821\text{ km})^3 = 2.529 \times 10^{10}\text{ km}^3$

Io surface area/ volume ratio

$= (4.167 \times 10^7\text{ km}^2) / (2.529 \times 10^{10}\text{ km}^3)$

$= 1.647 \times 10^{-3}\text{ km}^{-1}$ (to 4 sig. figs)

Now $(1.647 \times 10^{-3}\text{ km}^{-1}) / (4.709 \times 10^{-4}\text{ km}^{-1}) = 3.50$ [*units cancel*]

So the surface area to volume ratio of Io is 3.5 times greater than that of the Earth, so Io will lose its internal heat more efficiently than the Earth, since there is more surface area per unit mass for the heat to escape through.

Question 3

(a) (i) From the limited element data provided in *An Introduction to the Solar System*, Figure 2.2, the graph reveals that the three elements most abundant in CI carbonaceous chondrites are, in decreasing order, Magnesium (Mg), Silicon (Si), and Iron (Fe).

(ii) The three elements most scarce in CI carbonaceous chondrites are, in increasing order, Indium (In), Cadmium (Cd), and Europium (Eu).

(b) CI carbonaceous chondrites contain elements present in the same proportions as those determined for the Sun, and they do not appear to have been affected by any secondary alteration to their chemistry (e.g. differentiation or melting processes) since their formation.
(It is on the assumption that they represent the condensation of primitive nebula material that their age (c. 4.55 Ga) is taken as the age of terrestrial bodies in the solar system). (Fig. 2.2; p.36, 51).

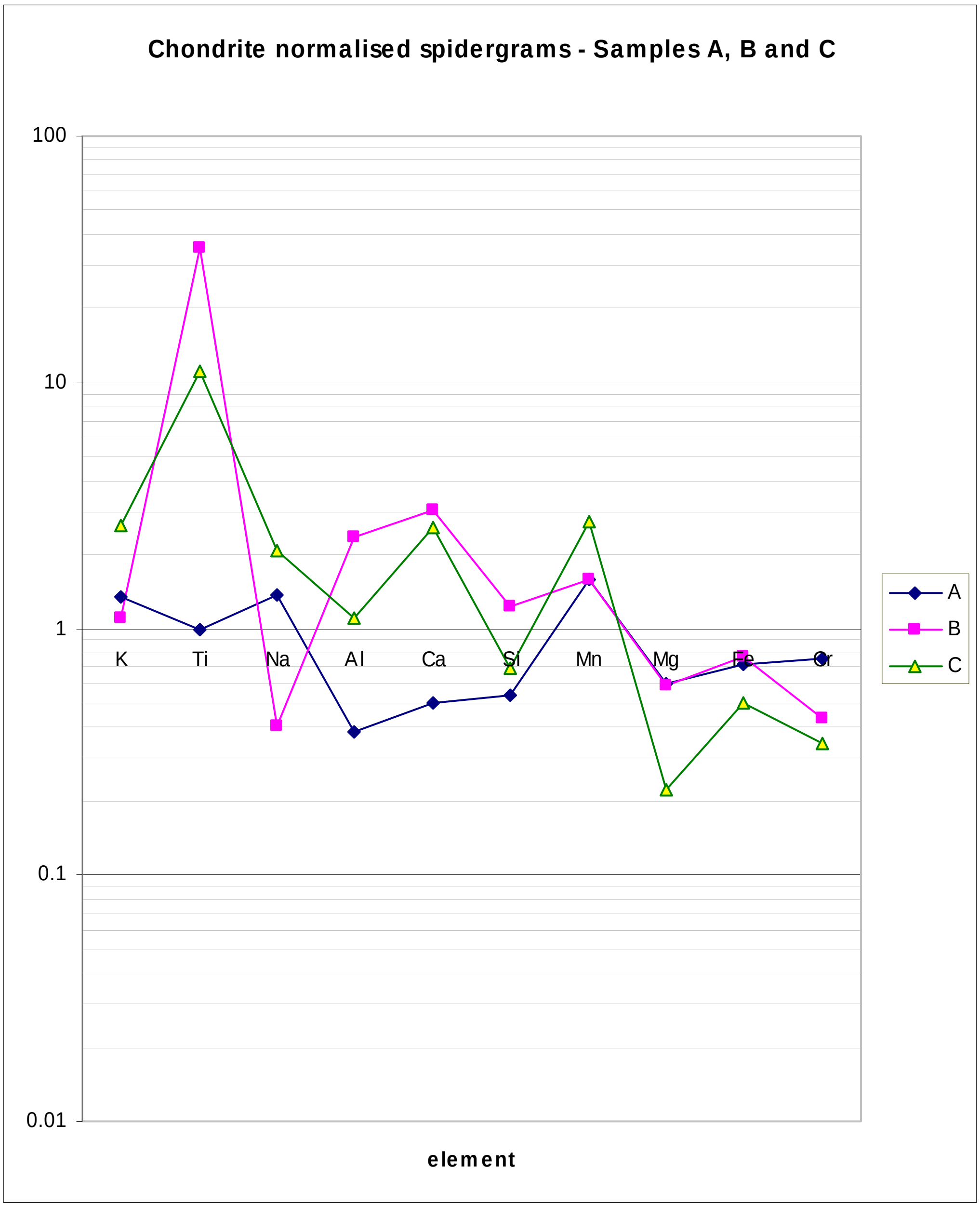
(c) Table 2 Correct normalised values to 3 significant figures given in bold

Table 2 - Completed

Element (ppm)	**Chondrite**	**A L-group Chondrite**	**B Lunar Basalt**	**C Shergotite**	*Chondrite normalized value (A)*	*Chondrite normalized value (B)*	*Chondrite normalized value (C)*
Si	162117	86621	199607	112191	**0.534**	**1.23**	**0.692**
Ti	445	438	15600	4900	**0.983**	**35.1**	**11.0**
Al	17359	6616	40752	19264	**0.381**	**2.35**	**1.11**
Fe	212772	151360	165070	105617	**0.711**	**0.776**	**0.496**
Mn	1471	2323	2323	4010	**1.58**	**1.58**	**2.73**
Mg	151188	90882	88047	33651	**0.601**	**0.582**	**0.223**
Ca	19082	9577	57890	49028	**0.502**	**3.03**	**2.57**
Na	3709	5045	1484	7641	**1.36**	**0.40**	**2.06**
K	545	739	600	1440	**1.36**	**1.10**	**2.64**
Cr	3975	3011	1727	1350	**0.534**	**1.23**	**0.692**

(d) Correctly plotted graph of normalised data:

Figure 1



(For Reference see: *An Introduction to the Solar System*, Section 2.2.1, Question 2.3)

(e) Sample A is an example of an L-Group chondrite
Sample B is lunar basalt
Sample C is a ‘Shergotite’ a Martian meteorite’

Chondritic meteorites have broadly similar compositions. Accordingly chondrite normalised values for element concentrations in a chondritic meteorite should approach unity (i.e. 1). Of the three unknown examples, the normalised values for pattern A are nearest unity, though this L-Group (i.e. low Fe) chondrite is relatively depleted in Fe and other elements.

Lunar basalt has high Ti values, and a low Na content (as stated in the question): Sample B has the highest Ti and lowest Na values.

As indicated in the question, of the three samples, the Martian meteorite is the most enriched in K and Na relative to chondritic values.

Question 4

(1) Completed Table 2

	Venus	Mars	Europa	Ganymede
Crater Name	***Golubkina***	***Yuty***	***Tyre***	***Nergal***
Central uplift peak (Y/N)	yes	yes	yes	yes
Collapse terraces (Y/N)	yes	yes	yes	yes
Crater type (simple/complex/basin)	complex	complex	basin	complex

For information: The images of craters, together with information from *An Introduction to the Solar System*, reveal the following:

Golubkina crater target is basalt (*An Introduction to the Solar System*, p. 118), the image reveals collapse terrace walls and central uplift.

Yuty crater crater target is basalt (An Introduction to the Solar System, p. 119), the image reveals probable collapse terraces and good central uplift.

Tyre impact basin target is dirty water ice as stated in the image caption (or dominantly water-ice crust; An Introduction to the Solar System, p. 81). The Tyre impact basin reveals rim collapse terraces and a possible central uplift peak.

Nergal crater target is icy (i.e. [water] ice with some rock materials r dominantly water ice, An Introduction to the Solar System, p. 13, 309). The image of the impact site reveals possible internal terraces, and central uplift peak.

Question 5

(ISS Ch 5)

(a) The troposphere is the lowest part of the atmosphere of terrestrial planets where the temperature decreases rapidly with altitude.
It is well mixed because conditions are favourable for convection to occur.

(b) As the parcel of air rises, the surrounding atmospheric pressure decreases, and so the parcel of air expands, and thus its temperature decreases.
Thus the temperature of the troposphere decreases with altitude.
The minimum rate of cooling with altitude would occur if no heat loss occurred from the parcel of air to the surrounding air – this minimum rate of cooling is called the adiabatic lapse rate. (ISS pp. 174-175)

(c) The height of Everest is 8.8 km, and the rate of cooling with altitude (i.e. the adiabatic lapse rate (ISS p. 175)) is $9.8\ \text{K km}^{-1}$, and so the temperature of the atmosphere will cool by:
$9.8\ \text{K km}^{-1} \times 8.8\ \text{km} = 86\ \text{K}$ (equivalent to a cooling of 86 ºC) to 2 significant figures. (cooling 86.24 K to 4 s.f.)
Given the sea level temperature is 25 ºC, then the air temperature at the summit of Everest is
25 ºC – 86 ºC = –61 ºC to 2 sig. figs. (= 212 K)

Implicit here is the assumption that up to the summit, the atmosphere cools at the adiabatic lapse rate.

(d) The temperature at which water boils, that is, goes from liquid/gas in equilibrium to gas phase only, is 69 ºC at the summit of Everest. The temperature in kelvin is 69 ºC + 273 ºC = 342 K
Reading off ISS Figure 5.31, one can estimate the vapour pressure of water at this temperature to be about 0.3 bar. Since the water is boiling at this temperature, the atmospheric pressure above the water must be at most 0.3 bar, hence the atmospheric pressure at the summit of Everest is 0.3 bar.

An answer between 0.2 and 0.5 bar would be acceptable. Answer should only be to 1 significant figure – higher is not justifiable. Beware that the y-axis on Fig. 5.31 has TWO powers of ten per tick mark.

(e) The warming of the atmosphere with height in the stratosphere requires a mechanism for the air to absorb radiation. Such a mechanism is the formation and destruction of ozone (or O_3). The reaction scheme (not required) is given in ISS Ch. 5 p. 183 Equations 5.10 – 5.13.
This is unique to Earth compared to the other terrestrial planets as the others with significant atmospheres (Venus and Mars) have insignificant levels of oxygen in their atmospheres. Hence, ozone formation is negligible and stratospheric heating cannot take place.
Convective mixing cannot take place in the stratosphere, since a parcel of air rising in the stratosphere will cool according to the adiabatic lapse rate.

However, it will then be always cooler than the surrounding air and, as stated in ISS Ch.5 P. 175, convection will only take place if the rising air parcel is always warmer than the surroundings.

Question 6

(ISS Ch 6)

(a) *There were many ways in which you could have earned the marks here* (see p 201)
Giant planets have no discernable surface, and are almost entirely gaseous/liquid.
You may also mention higher masses and/or radii or a predominantly H_2 and He atmosphere as defined from Table A1 in ISS (Appendix A, p. 376).
They have low mean density (lower than terrestrial planets) (Appx A)

You might also mention faster rotation relative to Earth as defined from Table A1 in ISS (Appendix A, p. 376), or strong magnetic fields/magnetosphere (pp.230-232, p.240), or large families of satellites (Table A1).

(ii) The bottom of the atmosphere (i.e. the 'surface') is defined as the altitude at which the pressure is 1 bar (p. 202).

(b) Radio waves can be emitted from a spacecraft and refracted through planetary atmospheres towards the Earth.
The amount of refraction of the radio signal that occurs during its path through the atmosphere is dependent upon the refractive index of the atmospheric gases, which in turn is related to the average molecular mass (pp. 215 and 216).

(c) *Wavelengths*: Ultraviolet (UV), Visible, Infrared (IR)
Alternative method: Mass spectrometer

(d) (i) Helium occurs as an atom and so has no bonds to vibrate and thus no vibrational spectrum *Or* (see p.215) the He UV spectrum occurs in a part of the UV not usually covered by instruments (and where it is hard to work)
The abundance of helium present is deduced by assuming solar abundances and subtracting the fraction of hydrogen detected, leaving the fraction due to helium. (p. 215)

(ii) Average relative molecular mass M_r is (based on ISS p.216):

$$M_r = (relative\ abundance\ 1 \times molecular\ mass\ 1)$$
$$+ (relative\ abundance\ 2 \times molecular\ mass\ 2)$$

Therefore:

$$M_r = (0.82 \times 2.0) + (0.18 \times 4.0)$$
$$= 2.36$$
$$= 2.4$$

(iii) The average mass (M_{av}) in kg is given by the product of the average relative molecular mass with the mass of a hydrogen atom (ISS p.216).

Or 1/12th the mass of ^{12}C (ISS p.162)

Therefore:

$$M_{av} = 2.36 \times 1.67 \times 10^{-27}\,kg$$
$$= 3.94 \times 10^{-27}\,kg$$
$$= 3.9 \times 10^{-27}\,kg$$

If M_r *= 2.4 is used from (ii), the 2 s.f. result is* 4.0×10^{-27} *kg*

(e) Using pp. 216-7 and Appendix B2:

The temperature is given by:

$$T = \frac{PM_{av}}{k\rho}$$

Where $P = 1\text{ bar} = 10^5\text{ Pa}$ is the given pressure

$M_{av} = 3.94 \times 10^{-27}$ kg from part (d)

$k = 1.38 \times 10^{-23}\text{ J K}^{-1}$ is the Boltzmann constant

$\rho = 0.65\text{ kg m}^{-3}$ is the given density at $P = 1$ bar.

So $$T = \frac{10^5\,\text{N m}^{-2} \times 3.94 \times 10^{-27}\,\text{kg}}{1.38 \times 10^{-23}\,\text{J K}^{-1} \times 0.65\,\text{kg m}^{-3}}$$

$$= 43.9 \frac{\text{N m}^{-2}\ \text{kg}}{\text{N m K}^{-1}\ \text{kg m}^{-3}}$$ (where 1 J = 1 N m)

= 44 K (2 significant figures. and cancelling units)

Question 7

(a) Definitions paraphrased from p. 246.

(i) aphelion – the point on an orbit furthest from the Sun.

(ii) perihelion - the point on an orbit closest to the Sun.

(iii) major axis – line bisecting the orbit and passing through both foci of the orbit.

(iv) semi-major axis – half the length of the major axis.

(v) eccentricity – the ratio of the distance of a focus from the centre of the orbit to the semi-major axis (also accept a measure of the elongation of the orbit).

(b) As defined on pp. 245 and 247.

Kepler's 1st Law: Planets move in elliptical orbits, with the Sun at one focus.

Kepler's 2nd Law: A line connecting the Sun to a planet would sweep out equal areas of space in equal times.

Kepler's 3rd Law: The square of a planet's orbital period is proportional to the cube of its semi-major axis.

The 3rd law is defined as an equation on p. 248 (equation 7.3), where P is the orbital period, a is the semi-major axis and k is a constant of proportionality:

$$P^2 = ka^3$$

If the unit of P is years (y) and the unit of a is AU, then the unit of the constant of proportionality k is $y^2\ AU^{-3}$.

(c) (i) Definitions as per equations 7.1, 7.2 and 7.3.
Perihelion (q):

$$q = a(1-e)$$
$$= 3.1 \times (1-0.60)$$

$$= 1.2 AU$$

Aphelion (Q):

$$Q = a(1+e)$$
$$= 3.1 \times (1+0.6)$$
$$= 5.0 AU$$

Orbital period (P):
$$P = \sqrt{ka^3}$$
$$= \sqrt{1 \times 3.1^3}$$
$$= 5.5\ years$$

(ii) This asteroid probably could not pose a threat to Earth.

q is > 1 A.U., i.e. the perihelion distance is greater than the aphelion distance for Earth, therefore the orbit will never cross that of Earth's.

However, perturbation by Jupiter is possible over time since Q=5.0 A.U. (i.e. close to Jupiter perihelion), which could change the orbit to pose a threat to Earth.

(d) For non-spherical bodies, the cross-sectional area as viewed from Earth changes as a function of rotation. This in turn leads to a variation in the amount of light reflected by the body (and subsequently observed). Elongated bodies result in large amplitudes in the lightcurve, and the spin rate can be deduced from the period of the lightcurve.

(e) As defined on p. 256, the red appearance indicates better reflectance at longer wavelengths, pointing to a D-type taxonomic class. For this class, albedo values between 0.02 to 0.05 are expected (Table 7.1).

Note that a semi-major axis of 3.1 AU is small for a D-type asteroid.

Alternative acceptable answer: could be S-type (which is red in the visible range though the reflectance does not continue to climb into the IR, Fig 7.11), albedo range 0.10 to 0.22. Semimajor axis 3.1 AU is large for an S-type

Question 8

This is an example of a good answer. There would of course be other equally good ways of framing the account.

(Section 1)

This short account briefly describes a model for the Solar Nebula, and the formation of the early Solar System as suggested by this model. It includes a summary of the key evidence supporting the solar nebula model, and the uncertainties associated in our understanding of Solar System formation.

(Section 2)

The Solar Nebula model describes a cloud of dust and molecular gas that collapses under its own gravity to make a circumstellar disk. The cloud will have enough mass to collapse if the force of gravity is greater than the pressure exerted by the gas molecules colliding with each other. This critical mass, the Jeans Mass, thus depends on high density and low temperature of the cloud. Other factors, including shock waves and magnetic fields, may affect the formation. To form a disk, the collapsing cloud must rotate. As the cloud collapses, the rotation speed increases due to the conservation of angular momentum.

The temperature gradient in the disk decreases outwards away from the hot young Sun, and the material in the disk follows a condensation sequence where the most refractive materials condense at high temperatures and the most volatile at low temperatures. The condensed grains then coagulate. As material is attracted to the protoSun at the centre of the disk, gravitational energy is converted to thermal kinetic energy (via collisions). The protoSun continues to contract under gravity, therefore increasing in temperature. It then moves to a T Tauri stage, when strong solar wind removes some of the material in the disk. Once the temperature is high enough to start nuclear fusion, contraction stops and the star is born.

Coagulated material impacts and accretes to form planetesimals, then gravitationally-driven runaway growth leads to the formation of planetary embryos. Volatile material for the inner planet atmospheres may have been delivered by impacting comets, replacing the gases removed by the T Tauri winds. The outer planets continue to accrete material longer than the inner planets, due to their larger planetary embryos and greater gravitational field.

(Section 3)

Key evidence for the solar system formation process comes from astronomical observations of nearby regions, which span the whole time sequence of events leading to solar system formation. Observations within our Solar System include meteorites and astronomical observations of the atmospheric composition of the outer planets.

Observations of star forming regions in dense dust clouds show they contain large volumes of material, and are relatively hot due to the young stars present. The most relevant are the stars with similar mass to our Sun. Much less massive stars could not support planetary systems; more massive stars would burn out quickly as

supernovae.
Isotope ratio data from meteorites help date the start of the formation of the solar system, and provide information on the composition of the circumstellar disk.

It is thought that the giant planets formed from larger embryos because they formed far enough from the Sun for water to condense, providing more solid material to accrete. However observations of nearby planetary systems, with “hot Jupiters” orbiting close to the star, suggest that planets can migrate during formation. This could explain the measurements of volatile elements in Jupiter’s atmosphere, which suggest that it formed at colder temperatures than its location suggests.

However Jupiter has more hydrogen and helium than the other outer planets. This is evidence for the T Tauri phase, since they formed further from the Sun and later than Jupiter, so could not accrete the hydrogen and helium removed by the T Tauri winds. There are many uncertainties in our understanding of our Solar System’s formation. The initial mass of the circumstellar disk is controversial since it is not clear whether small or large amounts of material were ejected during its formation. The Sun’s anomalously low angular momentum was transferred to the planets through viscous drag, but detailed explanations are not yet available. The complex sequence in which the condensation, coagulation, planetesimal formation, planetary embryos and planetary growth occurred is not well understood.

(Section 4)

The Solar Nebula model thus provides a model for the formation of the Solar System which is well supported by observations. Some uncertainties remain, particularly in the detailed understanding of Solar Nebula formation and evolution, including how planetary migration may have occurred.

Question 9

(a) Three main classes of meteorites: irons, stones, and stony-irons
Irons (or Iron meteorites) are predominantly composed of iron metal.
Stones (or stony meteorites) are composed mostly of silicate minerals.
Stony-iron meteorites are mixtures of metals and silicates.
ISS, p. 320.

(b) Reflectance spectroscopy (or measuring the brightness of reflected sunlight at different wavelengths) is the most commonly used technique to link specific meteorite type with an asteroid.

For example, the reflectance spectra of C-type asteroid most closely resembles carbonaceous chondrites
(Also accept correct examples with S-type and M-type asteroids). ISS p.322

(c) CAIs are white mineral inclusions rich in refractory elements found in meteorites

The three main theories are:
(1) CAIs were the first minerals to form from the cooling solar nebula as

mineralogy of these refractory inclusions matches very well with what is predicted to form at high temperatures in the condensation sequence.

(2) CAIs may represent evaporation residues consisting of agglomeration of minerals that lost all traces of volatile materials through heating and evaporation

(3) CAIs are unmelted pre-solar material

Scientists employ two main techniques to distinguish between competing theories for the origin of CAIs:

(1) age-dating (or radiometric dating) using short-lived radionuclides and
(2) measuring stable isotope compositions, especially oxygen isotopes. [ISS, p. 327-334]

(d) The x-wind model is an extension of the Solar Nebula model described in Chapter 8.
It provides a mechanism for producing material formed at high temperatures and included in [unmelted] chondritic meteorites, i.e. chondrules and CAIs. [pp335-6]

Young stellar objects emit a lot of x-rays, which are thought to be due to magnetic activity near the surface. [p336]

The x-wind model proposes that the magnetic fields surrounding the young star form an 'x-region' at the inner edge of the accretion disc, close to (about 0.075 AU from) the star.

From the x-region, material is channelled along the magnetic field, either into the star via the 'funnel flow', or away from the star and disc by the x-wind. [Fig 9.18 p337]. [a decently labelled diagram would help the answer here]

Dust from the disc falling in towards the star is heated and melted by the stellar radiation as it approaches the x-region. About two thirds of this material continues into the star via the funnel flow, but the remaining third is transported by the x-wind to more distant parts of the solar system where it is cool enough for the material to solidify and for chondrites to form. [p337]