Introductory Astronomy **NAME:**

Homework 10: Solar System Formation: Homeworks and solutions are posted on the course web site. Homeworks are **NOT** handed in and **NOT** marked. But many homework problems ($\sim$ 50–70 %) will turn up on tests.

Answer Table Name:

	a	b	c	d	e		a	b	c	d	e
1.	O	O	O	O	O	37.	O	O	O	O	O
2.	O	O	O	O	O	38.	O	O	O	O	O
3.	O	O	O	O	O	39.	O	O	O	O	O
4.	O	O	O	O	O	40.	O	O	O	O	O
5.	O	O	O	O	O	41.	O	O	O	O	O
6.	O	O	O	O	O	42.	O	O	O	O	O
7.	O	O	O	O	O	43.	O	O	O	O	O
8.	O	O	O	O	O	44.	O	O	O	O	O
9.	O	O	O	O	O	45.	O	O	O	O	O
10.	O	O	O	O	O	46.	O	O	O	O	O
11.	O	O	O	O	O	47.	O	O	O	O	O
12.	O	O	O	O	O	48.	O	O	O	O	O
13.	O	O	O	O	O	49.	O	O	O	O	O
14.	O	O	O	O	O	50.	O	O	O	O	O
15.	O	O	O	O	O	51.	O	O	O	O	O
16.	O	O	O	O	O	52.	O	O	O	O	O
17.	O	O	O	O	O	53.	O	O	O	O	O
18.	O	O	O	O	O	54.	O	O	O	O	O
19.	O	O	O	O	O	55.	O	O	O	O	O
20.	O	O	O	O	O	56.	O	O	O	O	O
21.	O	O	O	O	O	57.	O	O	O	O	O
22.	O	O	O	O	O	58.	O	O	O	O	O
23.	O	O	O	O	O	59.	O	O	O	O	O
24.	O	O	O	O	O	60.	O	O	O	O	O
25.	O	O	O	O	O	61.	O	O	O	O	O
26.	O	O	O	O	O	62.	O	O	O	O	O
27.	O	O	O	O	O	63.	O	O	O	O	O
28.	O	O	O	O	O	64.	O	O	O	O	O
29.	O	O	O	O	O	65.	O	O	O	O	O
30.	O	O	O	O	O	66.	O	O	O	O	O
31.	O	O	O	O	O	67.	O	O	O	O	O
32.	O	O	O	O	O	68.	O	O	O	O	O
33.	O	O	O	O	O	69.	O	O	O	O	O
34.	O	O	O	O	O	70.	O	O	O	O	O
35.	O	O	O	O	O	71.	O	O	O	O	O
36.	O	O	O	O	O	72.	O	O	O	O	O

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001 qmult 00007 1 4 1 easy deducto-memory: reading-homework-self-testing done 2

1. Did you complete reading-homework-self-testing for the Introductory Astronomy Lecture (IAL) by the weekly due date?

   a) YYYessss! b) Jawohl! c) Da! d) Sí, sí. e) OMG no!

   SUGGESTED ANSWER: (a),(b),(c),(d)

   Wrong answers:

   e) As Lurch would say AAAARGH.

   Redaction: Jeffery, 2008jan01

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010 qmult 00090 1 4 3 easy memory: evidence of Solar System formation

2. We will probably never be able to understand how our Solar System formed in exact detail, but can understand in more general terms how it formed by relying on various kinds of evidence: e.g.,

   a) star formation regions that we observe, extrasolar planetary systems (of which **399** are known as of 2023jun23), relics of the formation process (e.g., leftover planetesimals or fragments thereof including primitive meteorites), and **DINOSAUR FOSSILS**.
   b) star formation regions that we observe, extrasolar planetary systems (of which **3992** are known as of 2023jun23), relics of the formation process (e.g., leftover planetesimals or fragments thereof including primitive meteorites), and **BIOLOGY**.
   c) star formation regions that we observe, extrasolar planetary systems (of which **3992** are known as of 2023jun23), relics of the formation process (e.g., leftover planetesimals or fragments thereof including primitive meteorites), and **MODELING**.
   d) star formation regions that we observe, extrasolar planetary systems (of which **3** are known as of 2023jun23), relics of the formation process (e.g., leftover planetesimals or fragments thereof including primitive meteorites), and **MODELING**.
   e) star formation regions that we observe, extrasolar planetary systems (of which **399** are known as of 2023jun23), relics of the formation process (e.g., leftover planetesimals or fragments thereof including primitive meteorites), and **WISHFUL THINKING**.

   SUGGESTED ANSWER: (c)

   Wrong answers:

   e) If only wishful thinking actually worked.

   Redaction: Jeffery, 2001jan01

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010 qmult 00095 1 4 1 easy deducto-memory: Anthropic principle

3. "Let's play *Jeopardy*! For $100, the answer is: This principle (i.e., which is really a guiding hypothesis) explains coincidences in physics and in the universe that are favorable to life by stating that without these coincidences we would not be here to observe the universe. The opposite point of view is that such coincidences were dictated by the strict physical necessity of some underlying theory of everything. Of course, if the second view is correct, one wonders why the theory of everything in itself happens to be compatible with life (i.e., be biophilic)."

   What is the ____________ Principle, Alex?

   a) Anthropic b) Copernican c) Cosmological d) Biophilic e) Peter

   SUGGESTED ANSWER: (a)

   Wrong answers:

   b) This principle is that we Earthlings occupy an ordinary place in the universe.
   c) This principle is the hypothesis that the universe is homogeneous and isotropic when one considers the average behavior of large enough regions. As far as we can observe this hypothesis is confirmed by observations, but the large regions have to be very large: i.e., of order 100 Mpc and the observable universe only has a radius of order 4300 Mpc.
   d) This is not a standard term, but may be what should be used in place of the Anthropic Principle.

e) Back in the 1970's this fellow named Peter wrote a popular book called *The Peter Principle* in which he demonstrated that people tended to be promoted to their level of incompetence. As a predictive theory it is pretty feeble stuff, but one can always find victims of it. It was sort of like pet rocks—don't ask.

Redaction: Jeffery, 2001jan01

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010 qmult 00097 2 4 5 moderate deducto-memory: Kant's nebular hypothesis

4. "Let's play *Jeopardy*! For $100, the answer is: He/She was the first proposer of the nebular hypothesis for the origin of the Solar System in the context of Newtonian physics."

   Who is ____________, Alex?

   a) composer Johann Sebastian Bach (1685–1750) b) adventurer and writer Giovanni Jacopo Casanova (1725–1798) c) astronomer Caroline Herschel (1750–1848) d) English general and statesman John Churchill, Duke of Marlborough (1650–1722) e) philosopher Immanuel Kant (1724–1804)

SUGGESTED ANSWER: (e)

The nebular hypothesis has a sort of long prehistory with various ideas that are sort of it in different contexts. Democritus (460?–370? BCE) in Greco-Roman antiquity, Descartes in the 17th century, and Swedenborg in the 18th century. So it's hard to give absolute priority to any one person. Still Immanuel Kant seems the prioryist in the context of Newtonian physics.

Wrong answers:

a) Da, da, da, da. No that was Beethoven.
b) I don't think Casanova had any mathematical interests, but he did obtain a doctorate of laws from the University of Padua: unfortunately, no record of this degree has been found.
c) She was a comet hunter and a helpmeet (eek!!!) to her brother William Herschel the leading observational astronomer of the 18th century.
d) An ancestor of Winston Churchill: "He never walked off a battle field save as a victor; he never besieged a place he did not take."

Redaction: Jeffery, 2001jan01

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010 qmult 00100 1 1 1 easy memory: radioactive dating

5. Radioactive dating:

   a) uses radioactive decay to determine age.
   b) uses radioactive decay to determine mass.
   c) is useless in practice.
   d) uses radioactive decay to determine the half-life of a radioactive isotope.
   e) sounds more exciting than it is.

SUGGESTED ANSWER: (a)

Wrong answers:

b) Even the term "radioactive dating" suggests this is wrong.
c) Then why would we discuss it?
d) Radioactive dating uses half-lives, it doesn't determine them.
e) Arguably true, but not the best answer in the context of the course.

Redaction: Jeffery, 2001jan01

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010 qmult 00110 2 5 3 moderate thinking: radioactive dating, half-life

6. Radioactive dating of a rock gives the:

   a) age of the radioactive isotopes in the rock.
   b) time since the rock was last exposed to sunlight.
   c) time since the rock was formed provided the pre-formation daughter element abundance **CAN** be distinguished from the post-formation daughter element abundance.
   d) time since the rock was formed even when the pre-formation daughter element abundance **CANNOT** be distinguished from the post-formation daughter element abundance.

e) time since the rock was last exposed to radioactivity.

SUGGESTED ANSWER: (c)

I probably didn't talk about this in class. One has to read the book and use some understanding too. Note Ze-158 confirms that the technique is called radioactive dating.

Wrong answers:
a) Students wouldn't know this, but nuclei of the same element are essentially identical in quantum theory. They don't have the degrees of freedom to be individually characterized. Decay is a random process: a radioactive nucleus formed a second ago and one formed 10 Gyrs ago have exactly the same probability of decay in theory. The ages of individual nuclei cannot be determined by internal means in principle. But this answer can be ruled out since it means that radioactive dating doesn't give the age of the rock.
c) A red herring and it wouldn't give the rock's age.
d) if the radioactive isotopes in the rock and their daughter product stable isotopes from an earlier existence were mixed together at the time of formation, then simple comparison of the ratio of radioactive element and daughter element abundance wouldn't give the age of the rock.
e) But this wouldn't give the rock's age.

Redaction: Jeffery, 2001jan01

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010 qmult 00210 1 1 4 easy memory: half-life probability

7. Say you have a radioactive nucleus with half-life $t_{1/2}$. You've observed it for n half-lives. What is the probability that it will decay in the next half-life? **HINT:** Think about tossing coins.

a) 1. b) 0. c) $1 - 1/2^{n+1}$. d) 1/2. e) $1 - 1/2^n$.

SUGGESTED ANSWER: (d)

It's like flipping a coin. It doesn't matter how many heads you had in a row, you still have only a 50 % chance of tail on the next throw. In principle, you could go on flipping a coin all day and only get heads Statistically unlikely, but it could happen In fact, it has. Tom Stoppard reports that *Rosencrantz and Guildenstern are Dead* that Rosencrantz and Guildenstern played coin flips and Rosencrantz won on heads 92 times in row. This caused Guildenstern to wonder if Rosencrantz was cheating—or that the universe was.

Wrong answers:
c) A specious answer.

Redaction: Jeffery, 2008jan01

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010 qmult 00300 1 3 1 easy math: radioactive dating/decay K-40

8. You have a sample of rock in which the ratio of ^{40}K (radioactive potassium) to ^{40}Ca (stable calcium) is 1 to 1. The half-life of ^{40}K is about 1.3 billion years. Assuming the rock was calcium-free at formation, what is the approximate time since the rock was formed?

a) 1.3 billion years. b) 2.6 billion years. c) Only a few years at most.
d) 13 billion years. e) 4.6 billion years.

SUGGESTED ANSWER: (a) People do need to remember what half-life means.

Wrong answers:
e) This is the current age of the Solar System.

Redaction: Jeffery, 2001jan01

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010 qmult 00400 1 3 1 easy math: radioactive dating, half-life U-238

9. A sample is initially pure radioactive $^{238}_{92}$U (isotope uranium-238). After four half-lives how much $^{238}_{92}$U is left?

a) 1/16. b) 1/2. c) 1/4. d) 1/10. e) None.

SUGGESTED ANSWER: (a)

People do need to remember what half-life means. For the half-life of $^{238}_{92}$U see Enge-225.

Wrong answers:

e) Formally this only happens at infinite time for the ideal case of an infinite sample. But in fact for a finite sample many half-lives along you will reach a point where the formula predicts a fraction of an undecayed nucleus remaining. At that point the last nucleus is gone or will be in a finite (though perhaps) very long time.

Redaction: Jeffery, 2001jan01

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010 qmult 00610 1 4 2 easy deducto-memory: decay energy conversion, Christmas

10. In dense environments, decay energy from radioactive decay is usually converted into:

a) macroscopic kinetic energy. b) heat energy. c) macroscopic gravitational potential energy. d) macroscopic magnetic field energy. e) reindeer energy.

SUGGESTED ANSWER: (b)

Wrong answers:

e) This is the Christmas answer.

Redaction: Jeffery, 2001jan01

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010 qmult 00800 1 1 1 easy memory: nebular hypothesis

11. The planets probably formed out of:

a) a disk of gas and dust that surrounded the early Sun or proto-Sun.
b) material pulled out of the Sun by a star that passed closely in the remote past.
c) pure hydrogen gas.
d) pure helium gas.
e) carbon dioxide gas.

SUGGESTED ANSWER: (a)

Wrong answers:

b) This hypothesis had a vogue for a few decades back in the early part of the 20th century.

Redaction: Jeffery, 2001jan01

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010 qmult 00810 1 1 4 easy memory: planets form out of a protoplanetary disk

12. The planets orbit approximately in a single plane probably because:

a) the early solar nebular magnetic field forced them to form in a plane.
b) pure luck.
c) pure bad luck.
d) they formed out of the protoplanetary disk of material that formed about the proto-Sun.
e) a passing star pulled them into a plane long after formation.

SUGGESTED ANSWER: (d)

Wrong answers:

e) This theory had a vogue once in the early decades of the 20th century, but now is out of date.

Redaction: Jeffery, 2001jan01

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010 qmult 00900 2 5 2 moderate thinking: Sun's volatiles

13. Volatiles could not condense much in the inner Solar System, and thus did not get incorporated in massive amounts into the inner planets. But the Sun is mainly hydrogen and helium which are certainly volatiles. Why in the Sun and not in the inner planets?

a) Because of the Sun's magnetic field.
b) The proto-Sun grew massive enough to hold its volatiles by **GRAVITATION** despite the high temperature it reached.
c) The proto-Sun grew massive enough to hold its volatiles by the **PRESSURE FORCE** despite the high temperature it reached.
d) The hydrogen and helium that went into the Sun was sticky.
e) The difference has no plausible explanation.

SUGGESTED ANSWER: (b)

Wrong answers:
c) The pressure force is trying to push matter out of the Sun.

Redaction: Jeffery, 2001jan01

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010 qmult 01000 2 3 1 moderate math: solar wind flushing

14. The solar wind probably flushed much of the primordial gas and dust out of the Solar System during its formation. Say that the solar wind has a speed of 400 km/s. Pluto is about 40 astronomical units from the Sun and the astronomical unit is about 1.5×10^{13} cm. How long does it take the wind to travel from the Sun to Pluto? About:

a) 1.5×10^7 s or half a year. b) 1.5×10^7 s or 10 years. c) 1.5×10^{13} s. d) 1×10^5 s or a day. e) 1×10^5 s or 10 day.

SUGGESTED ANSWER: (a)

Wrong answers:
b) 1.5×10^7 s is about half a year.
e) 1×10^5 s is about a day.

Redaction: Jeffery, 2001jan01

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010 qmult 01100 1 4 2 easy deducto-memory: planetesimals

15. Planetesimals are:

a) objects of kilometer size or greater that are always lost from the Solar System during planet formation.
b) objects of kilometer size or greater that can mutually accrete (largely because of gravitational attraction) to form protoplanets.
c) centimeter size grains that mutually accrete (largely because of gravitational attraction) to form protoplanets.
d) very tiny planets.
e) always made of ices.

SUGGESTED ANSWER: (b)

Wrong answers:
d) Well not really.

Redaction: Jeffery, 2001jan01

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010 qmult 01200 2 1 4 moderate memory: planetary formation sequence with streaming instability

16. The planetary formation sequence as currently understood is:

a) streaming instability (plus collective-self-gravitation accretion) changing gas to grains, condensation of grains to planetesimals, gravitational accretion of planetesimals to protoplanets.
b) streaming instability (plus collective-self-gravitation accretion) changing gas to planetesimals, further streaming instability (plus collective-self-gravitation accretion) changing planetesimals to protoplanets.
c) condensation of gas to grains, streaming instability (plus collective-self-gravitation accretion) changing grains to planetesimals, further streaming (plus instability/collective-self-gravitation accretion) changing planetesimals to protoplanets.
d) condensation of gas to grains, streaming instability (collective-self-gravitation accretion) changing grains to planetesimals, gravitational accretion of planetesimals to protoplanets.
e) gravitational coalescence of gas to grains, streaming instability (collective-self-gravitation) changing grains to planetesimals, gravitational accretion of planetesimals to protoplanets.

SUGGESTED ANSWER: (d)

This can be just a straight moderate memory question, but some thought can narrow the answers down. Gravity only plays a role in larger body structure. Gases condense.

Wrong answers:

e) Not condensation of grains to planetesimals.

Redaction: Jeffery, 2001jan01

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010 qmult 01300 2 4 5 moderate deduction: two planetesimals bind

17. Two planetesimals are most likely to totally bind together if:

   a) they are moving toward each other at high relative speed for a head-on collision.
   b) they are moving directly away from each other.
   c) they are at very different distances from the star or protostar.
   d) they are invisible.
   e) they approach each other with low relative velocity.

   SUGGESTED ANSWER: (e) Only answers (a) and (e) are plausible. Both the reading and lectures suggest that high speed head-on collisions would tend to be violent and shattering events.

   Wrong answers:
   b) This doesn't seem very likely to me
   d) They are not invisible.

   Redaction: Jeffery, 2001jan01

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010 qmult 01310 2 4 1 moderate deduction: two planetesimals fragment

18. Two planetesimals are most likely to fragment and **NOT** to bind together if:

   a) they are moving toward each other at high relative speed for a head-on collision.
   b) they are moving directly away from each other.
   c) they are at very different distances from the star or protostar.
   d) they are invisible.
   e) they approach each other with low relative velocity.

   SUGGESTED ANSWER: (a) Only answers (a) and (e) are plausible. Both the reading and lectures suggest that high speed head-on collisions would tend to be violent and shattering events.

   Wrong answers:
   b) This doesn't seem very likely to me
   d) They are not invisible.

   Redaction: Jeffery, 2001jan01

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010 qmult 01500 2 5 1 moderate thinking: where'd helium come from

19. What is the origin of the helium in the Sun's atmosphere, in the Sun's core, and in Jupiter?

   a) The helium in the Sun's atmosphere and Jupiter is **PRIMORDIAL**: i.e., it was the helium present when the Solar System formed: most of this primordial helium formed in the Big Bang (or so the theory goes) and some in earlier generations of stars. The helium in Sun's core is partially primordial and partially from the **NUCLEAR BURNING** of the hydrogen that goes on in the Sun's core.
   b) All this helium is **PRIMORDIAL**: i.e., it was the helium present when the Solar System formed: most of this primordial helium formed in the Big Bang (or so the theory goes) and some in earlier generations of stars.
   c) All the helium in the Solar System was formed in the **SUN'S CORE** by the nuclear burning of helium. Convection transported this helium to the surface of the Sun and the solar wind transported some of it into the outer solar system where of it got accreted onto the proto-Jupiter.
   d) All the helium in the Solar System was formed by nuclear burning of hydrogen that occurred **WHERE THE HELIUM IS NOW FOUND**. Thus, there was nuclear burning on the surface of the Sun and and in Jupiter in the early days of the Solar System. Of course, nowadays the nuclear burning of hydrogen occurs only in the Sun's core.
   e) The chemical breakup of **PRIMORDIAL WATER** (i.e., water that existed before the Solar System formed) left the helium in all of these sites.

   SUGGESTED ANSWER: (a)

I've thrown in some thought provoking (I hope) red herrings that could stimulate some thought on the part of the students. Earth's helium may be primarily from radioactive decay: i.e., α-decay. I've read that somewhere. I should check it out.

Wrong answers:
b) Nuclear burning in the Sun's core does produce new helium there.
c) Nah. The helium in the Sun's core mostly stays there. See Se-232.
d) Only the center of the Sun in the Solar System has ever been hot and dense enough to burn hydrogen, except for some small scale human-caused burning and maybe a few other small scale burnings.
e) Water is H_2O, not He_2O.

Redaction: Jeffery, 2001jan01

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010 qmult 01600 2 5 3 moderate thinking: ices and rocky material condense
20. In Solar System planetary formation:

a) the ices condensed mostly near the Sun; the rocky and metallic material in the outer Solar System.
b) the ices condensed everywhere; the rocky and metallic material in the inner Solar System only.
c) the ices condensed mainly in the outer Solar System. The rocky and metallic material condensed everywhere roughly speaking.
d) the ices condensed only near what became Jupiter. The rocky and metallic material condensed only in the neighborhood of what became the Earth.
e) the ices condensed only near what became Saturn. The rocky and metallic material condensed only in the neighborhood of what became the Earth.

SUGGESTED ANSWER: (c)

This can be reasoned out. Ices are volatile and arn't likely to condense near the Sun. Nonvolatiles (i.e., refractories) can condense both in the outer and inner regions: true there are variations among the nonvolaties: some are less nonvolatile than others: but the roughly speaking accounts for any pickiness.

Wrong answers:
e) Why only Saturn? Why only the Earth?

Redaction: Jeffery, 2001jan01

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010 qmult 01650 1 4 1 easy deducto-memory: gas giant formation
21. "Let's play *Jeopardy*! For $100, the answer is: These Solar System bodies are thought to form according to one of two possible theories. Theory 1: they start as rocky/icy protoplanets that are massive enough to gravitationally attract and hold abundant hydrogen and helium gas. Theory 2: they start as gravitationally collapsed dense cores of hydrogen and helium just as stars do and grow by further gravitational accretion of abundant hydrogen and helium."

What are ____________, Alex?

a) gas giant planets b) rocky or terrestrial planets c) minor planets or an asteroids
d) Kuiper Belt objects or a trans-Neptunian objects e) mirror matter planets

SUGGESTED ANSWER: (a)

Wrong answers:
a) Rocky planets do not have abundant hydrogen and helium and no thinks they start forming just like stars.
c) There is a theory–for which there is a shred of evidence even—that there is a mirror universe which interacts with our universe only be gravitation and few minor, obscure processes. In the mirror universe there are mirror planets that our just like ours one supposes.

Redaction: Jeffery, 2001jan01

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010 qmult 01800 1 1 3 easy memory: asteroids
22. Asteroids are:

a) very probably leftover **ICY** planetesimals (or planetesimal fragments) from the formation of the Solar System. Some have undergone internal-heat geological evolution.
b) very probably leftover **GASEOUS** planetesimals (or planetesimal fragments) from the formation of the Solar System.
c) very probably leftover **ROCKY** planetesimals (or planetesimal fragments) from the formation of the Solar System. Some have undergone internal-heat geological evolution. They may have some ice too.
d) **ICY** planetesimals that formed **OUTSIDE** of the Solar System. Some have undergone internal-heat geological evolution.
e) **ROCKY** planetesimals that formed **OUTSIDE** of the Solar System. Some have undergone internal-heat geological evolution.

SUGGESTED ANSWER: (c)

Actually, it is now thought that some asteroids probably have significant ice. But they are rockier than the icy bodies farther out in the Solar System.

Wrong answers:
a) Not icy.

Redaction: Jeffery, 2001jan01

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010 qmult 01810 1 4 1 easy deducto-memory: comet origins
23. Comets are:

a) very probably leftover **ICY/CARBONACEOUS** planetesimals (or planetesimal fragments) from the formation of the Solar System.
b) very probably leftover **ROCKY** planetesimals (or planetesimal fragments) from the formation of the Solar System.
c) very probably leftover **GASEOUS** planetesimals (or planetesimal fragments) from the formation of the Solar System.
d) **ICY/CARBONACEOUS** planetesimals that formed outside of the Solar System.
e) **ROCKY** planetesimals that formed outside of the Solar System.

SUGGESTED ANSWER: (a) HI-251 emphasizes that comets must be rather carbonaceous

Wrong answers:
b) Not rocky surely.

Redaction: Jeffery, 2001jan01

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010 qmult 01900 1 1 3 moderate deduction: heating by collapse and collision
24. Both gravitational collapse and collisions tend to cause:

a) cooling. The heat from the bodies gets transformed into bulk kinetic energy and gravitational potential energy.
b) plate tectonics.
c) heating. The gravitational potential energy and bulk kinetic energy of the bodies gets randomized into microscopic kinetic energy.
d) plate tectonics. The gravitational potential energy and bulk kinetic energy of the bodies sets up convective flows which brings magma to the surface of the protostars. The magma pushes about the crustal plates.
e) magnetic fields which then cause the bodies to explode apart.

SUGGESTED ANSWER: (c) I've thrown in some thought provoking (I hope) red herrings that could stimulate some thought on the part of the students.

Wrong answers:
d) Magma on protostars!

Redaction: Jeffery, 2001jan01

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010 qmult 01950 2 4 5 moderate deducto-memory: Seeds 4 stages of evolution

25. In one kind of analysis, the evolution of rocky/icy bodies in the solar system has been divided in to four stages. Not all rocky/icy bodies will go through all stages. These stages in probable time order are:

 a) nuclear differentiation, heavy bombardment, flooding by liquid nitrogen and/or liquid helium, and plate tectonics.
 b) nuclear differentiation, light bombardment, flooding by liquid nitrogen and/or water, and plate tectonics.
 c) nuclear differentiation, light bombardment, flooding by lava and/or water, and plate tectonics.
 d) chemical differentiation, light bombardment, flooding by lava and/or water, and plate tectonics.
 e) chemical differentiation, heavy bombardment, flooding by lava and/or water, and continuing geologic evolution.

SUGGESTED ANSWER: (e) This the schema of Se-428. I don't know if anyone else has used it, but maybe.

Wrong answers:
 d) Plate tectonics seems to be unique to the Earth, but no one talks of a light bombardment.

Redaction: Jeffery, 2001jan01

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010 qmult 02000 1 1 3 easy memory: chemical differentiation
26. In planet formation, the chemical differentiation stage is the stage:

 a) of heavy cratering.
 b) of heavy cratering and lava flows.
 c) where the molten materials of the early planets separated under the action of **GRAVITY**. The **DENSER** materials sank to the deeper regions; the **LESS DENSE** materials rose to the upper regions.
 d) where the molten materials of the early planets separated under the action of **MAGNETIC FIELDS**. The **DENSER** material sank to the deeper regions; the **LESS DENSE** materials rose to the upper regions.
 e) where the molten materials of the early planets separated under the action of the **SOLAR WIND**. The **LESS DENSE** material sank to the deeper regions; the **DENSER** materials rose to the upper regions.

SUGGESTED ANSWER: (c)

Is the process chemical differentiation? Well the process is physical, not chemical, but on the other hand it is the elements that differentiate and in this context chemical is a synonym element. Maybe elemental differentiation is a sensible expression, but since no one uses it, we won't either.

Wrong answers:
 e) Not the solar wind.

Redaction: Jeffery, 2001jan01

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010 qmult 02100 2 4 3 moderate deducto-memory: heavy bombardment
27. Mainly by studying the variations in lunar crater density per unit area and the variations in ages of rocks from the lunar highlands and maria, Solar System astrophysicists have concluded that there was a period of heavy bombardment by various Solar System bodies. This heavy bombardment:

a) was about 65 million years ago. b) was about 100 to 65 million years ago. c) covered about the first billion years of the Solar System after formation. d) was about 15 to 10 billion years ago. e) was coincident with the last ice age.

SUGGESTED ANSWER: (c) Even if the students can't recall the 4.6–3.8 Gyr ago period discussed in class, they should be able to rule out the other periods just by knowing the bombardment was early and the Solar System is about 5 Gyrs old. Of course, if someone is hooked on dinosaurs ... Some of the information in the preamble comes from FMW-175–176.

Wrong answers:
 e) Since we may still be in the last ice age isn't odd that we havn't noticed the heavy bombardment.

Redaction: Jeffery, 2001jan01

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010 qmult 02200 2 5 2 moderate thinking: cratering

28. Why is almost every Solar System body with a **SOLID** surface scarred by craters?

a) In the **10 BILLION YEARS** since the Solar System formed there has been a continuous increasing bombardment on solar system bodies by other Solar System bodies that was heaviest at early times in the heavy bombardment phase of the Solar System. Those bodies without solid surfaces can show impact effects only briefly. Those bodies with ongoing active geological activity (based on internal heat/erosion) erase traces of all but the most recent craters. But most solid-surface bodies do not have much active internal-heat/erosion-based geology. On these bodies cratering is principally erased only by newer cratering which does not of course erase the scarring.
b) In the **4.6 BILLION YEARS** since the Solar System formed there has been a continuous bombardment on solar system bodies by other Solar System bodies that was heaviest at early times in the heavy bombardment phase of the Solar System. Those bodies without solid surfaces can show impact effects only briefly. Those bodies with ongoing active geological activity (based on internal heat/erosion) erase traces of all but the most recent craters. But most solid-surface bodies do not have much active internal-heat/erosion-based geology. On these bodies cratering is principally erased only by newer cratering which does not of course erase the scarring.
c) The heaviest bombardment of Solar System bodies by other Solar System bodies has occurred in the last **100 MILLION YEARS**. This bombardment has cratered almost all the solid surfaces. It has also probably been responsible for the dinosaur extinction circa 65 million years ago. The likely deep impact of kilometer-scale asteroid 1997 XF_{11} on Earth in 2028 is just part of this bombardment phase.
d) Most solid bodies in the Solar System have suffered heavy continuous volcanism: the asteroids most of all. The craters are mostly volcanic, not impact, in origin.
e) The Earth isn't scarred by craters.

SUGGESTED ANSWER: (b) Only (a) and (b) should be in the running and (a) is wrong in two particulars.

Wrong answers:
c) Students probably know that JPL guy Don Yeomens leading a ragtag bunch of redneck grad students successfully dynamited 1997 XF_{11} out of path. Breathe easier humankind.
d) Volcanism on asteroids? Well there was some elemental differentiation, but it probably didn't include real volcanism.
e) This is true, but not an answer.

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010 qmult 02500 2 4 1 moderate deducto-memory: primordial-radiogenic heat geology

29. The rocky bodies in the Solar System from the largest asteroids upward in mass probably all experienced to some degree geological activity caused by:

a) internal heat from formation (i.e., primordial heat) and past and in some cases current radiogenic heating.
b) liquid water erosion.
c) hydrogen enbrittlement.
d) internal heat from the red giant phase of the Sun.
e) ice ages.

SUGGESTED ANSWER: (a)

Wrong answers:
b) Only Earth and Mars have had much liquid water erosion at least so far as we can tell now. I doubt that liquid water ever existed significantly on the large asteroids.
c) According to a graffito I once read in a washroom stall, hydrogen enbrittlement was the probable reason why the coat hook had broken off. Personally, I think they make those things out of the sludge at the bottom of a vat of chrome. Why not make them out of stainless steel?
e) As far as we know only Earth has had ice ages, but Mars may have had them too.

Redaction: Jeffery, 2001jan01