Introductory Astronomy

Homework 10: Solar System Formation Not to be handed in. Homework solutions are posted already.

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020 qmult 00090 1 4 3 easy memory: evidence of solar system formation

1. 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 planets (of which **111** are known as of 2004mar04), 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 planets (of which **1111** are known as of 2004mar04), 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 planets (of which **111** are known as of 200mar04), 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 planets (of which **2** are known as of 2004mar04), 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 planets (of which **111** are known as of 2004mar04), 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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020 qmult 00095 1 4 1 easy deducto-memory: Anthropic Principle

2. "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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020 qmult 00097 2 4 5 moderate deducto-memory: Kant's nebular hypothesis

3. "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 was _____, 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)

   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 a battle field save as a victor; he never beseiged a place he did not take."

   Redaction: Jeffery, 2001jan01

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020 qmult 00100 1 1 1 easy memory: radioactive dating

4. 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 nuclear species (i.e., a radioactive nuclide).
   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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020 qmult 00200 1 4 1 easy deducto-memory: half-life

5. A half-life is:

   a) the time it takes for **HALF** a sample of a radioactive species (i.e., a radioactive nuclide) to decay to a daughter nuclide.

b) the time it takes for **a QUARTER** of a sample of a radioactive nuclear species (i.e., a radioactive nuclide) to decay to a daughter nuclide.
c) the time between star and planet formation.
d) the age of the Sun.
e) the nuclear fuel burning life-time of the Sun.

SUGGESTED ANSWER: (a) Many people should know this from general knowledge especially in Nevada.

Wrong answers:
e) Why would it be called half-life if it is a quarter that has decayed.

Redaction: Jeffery, 2001jan01

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

6. 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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020 qmult 00500 1 5 3 easy thinking: radioactive dating, half-life

7. A sample was initially pure radioactive ^{238}U (an isotope of uranium). The half-life of ^{238}U is 4.5 billion years. Currently, only 1/128 of the sample is ^{238}U. How old is the sample?

a) 4.5 billion years old.
b) 4.5 million years old.
c) 31.5 billion years old. This is older than the currently estimated age of the universe $\sim$ 10–20 billion years old. Clearly there is an inconsistency.
d) 35 billion years old. This is older than the currently estimated age of the universe $\sim$ 10–20 billion years old. Clearly there is an inconsistency.
e) 15 billion years old. This age puts a lower limit on the age of the universe (i.e., the time since the Big Bang).

SUGGESTED ANSWER: (c) It takes 7 half-lives to reduce a sample to (1/128)th of its original abundance.
This is a math question with a bit of thinking.
For the half-life of ^{238}U see Enge-225.

Wrong answers:
a) This is what is left after one half-life.

Redaction: Jeffery, 2001jan01

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020 qmult 00610 1 4 2 easy deducto-memory: decay energy conversion

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

a) macroscopic kinetic energy. b) thermal (or 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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020 qmult 00810 1 1 4 easy memory: planets form out of a proplyd

9. 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 the 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 cnetury, but now is out of date.

Redaction: Jeffery, 2001jan01

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

10. 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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020 qmult 01000 2 3 1 moderate math: solar wind flushing

11. 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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020 qmult 01200 2 1 4 moderate memory: planetary formation sequence
12. The planetary formation sequence as currently understood is:

a) collective-self-gravitation/sticky accretion of gas to grains, condensation of grains to planetesimals, gravitational accretion of planetesimals to protoplanets.
b) collective-self-gravitation/sticky accretion of gas to grains, condensation of grains to planetesimals, second round of sticky accretion of planetesimals to protoplanets.
c) condensation of gas to grains, collective-self-gravitation/sticky accretion of grains to planetesimals, further sticky accretion of planetesimals to protoplanets.
d) condensation of gas to grains, collective-self-gravitation/sticky accretion of grains to planetesimals, gravitational accretion of planetesimals to protoplanets.
e) gravitational coalescence of gas to grains, collective-self-gravitation/sticky accretion of 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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020 qmult 01300 2 4 5 moderate deduction: two planetesimals bind
13. 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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020 qmult 01500 2 5 1 moderate thinking: where'd helium come from
14. 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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020 qmult 01650 1 4 1 easy deducto-memory: gas giant formation

15. "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 or Jovian 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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020 qmult 01800 1 1 3 easy memory: asteroids

16. 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.
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)

Wrong answers:
a) Not icy.

Redaction: Jeffery, 2001jan01

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020 qmult 01810 1 4 1 easy deducto-memory: comet origins
17. 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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020 qmult 01900 1 1 3 moderate deduction: heating by collapse and collision
18. 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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020 qmult 01950 2 4 5 moderate deducto-memory: Seeds 4 stages of evolution

19. 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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020 qmult 02100 2 4 3 moderate deducto-memory: heavy bombardment

20. 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 informations 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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020 qmult 02200 2 5 2 moderate thinking: cratering

21. 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.

Redaction: Jeffery, 2001jan01

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020 qmult 02500 2 4 1 moderate deducto-memory: residual/radioactive geology

22. 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 and past and in some cases current radioactive decay 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 off the sludge at the bottom of the vat of chrome. Why not make them out of steel.
e) As far as we know only Earth has had ice ages, but Mars may have had them too.

Redaction: Jeffery, 2001jan01