P100 University of Rochester NAME Soln key - SLM
S. Manly Spring 2009

P100 – Final Exam (May 5, 2009)

Please read the problems carefully and answer them in the space provided. Write on the back of the page, if necessary. Show your work where requested in order to be considered for partial credit. In problems where you are requested to show your work, no credit will be given unless your work is shown.

Problem 1 (true or false, each part is worth 2 points):

a) F 'Speed" and 'velocity' mean the same thing scientifically.
b) T Protons are made up of other, more fundamental, particles.
c) F The majority of the heavy elements on Earth were formed during the early stages of the big bang.
d) F Nuclear fission is the process that produces the energy in stars.
e) T In quantum mechanics, it is not possible to calculate the exact time that a particular radioactive nucleus will decay, even if you know the half-life for that nucleus.
f) F The rate of expansion of the universe is currently decreasing.
g) F A light-year is a unit of time used by astronomers and NASA.
h) T A Newton is a unit of force.
i) F Leptons are made up of combinations of two or three quarks.
j) T According to quantum field theory, the electromagnetic force is conveyed by the exchange of a virtual photon.
k) T Two nuclei with the same number of protons and different numbers of neutrons are known as 'isotopes'.
l) F Beta radiation is the same thing as gamma radiation, only slightly less energetic.
m) T According to modern cosmologists, most of the protons that make up the hydrogen in our universe were formed one microsecond after the big bang started.
n) F The cosmic microwave background is light that comes to us from the time that the light nuclei were formed during big bang nucleosynthesis.
o) T The apparent 'flatness' of space is one of the reasons cosmologists advocate theories that incorporate inflation.

Problem 2 (3 points):

MISTAKE - No correct Answer

When you are in a high-flying jet plane, does either your weight or your mass differ from their normal value as measured on the ground?

a) No, both your weight and your mass are exactly the same as when you are on the ground.
b) Both your weight and your mass are slightly increased.
c) You weight is slightly increased, but your mass is unchanged.
d) Both your weight and your mass are slightly reduced.
e) Your mass is slightly reduced, but your weight is unchanged.

Weight is slightly reduced + Mass is unchanged

All/any ANSWER or NO Answer gets full credit

Problem 3 (3 points):

The acceleration of the moon is

a) zero, because the moon is obviously not accelerating.
b) directed toward Earth.
c) directed along the moon's forward direction of motion.
d) directed outward away from Earth.
e) none of the above.

Scores
1. 30/30
2. 3/3
3. 3/3
4. 3/3
5. 3/3
6. 3/3
7. 3/3
8. 3/3
9. 5/5
10. 5/5
11. 6/6
12. 5/5
13. 5/5
14. 5/5
15. 6/6
16. 6/6
17. 6/6

Total 100/100

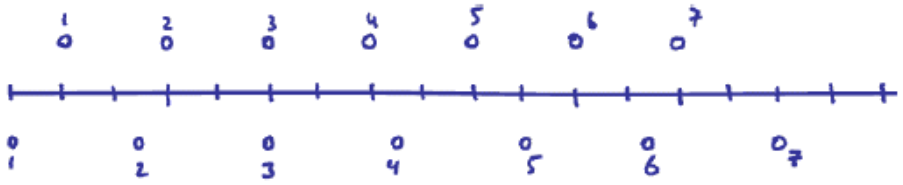
Holy crap! Incredible work!

Problem 4 (3 points):

According to astrophysicists, Earth originated

a) as one of Jupiter's moons.
b) during the big bang, when matter was compressed into stars and planets.
c) from gases gathered by the sun after the sun had already formed.
d) when a passing star tore off parts of the sun, and these parts condensed into the planets (including the Earth).
e) from the same collapsing gas cloud that coalesced into the sun.

Problem 5 (3 points):



The figure represents a multiple-flash photo (with a constant time interval between flashes) of two balls moving to the right, and shows both balls at several numbered times. In the figure,

a) both balls are accelerated, and the upper ball is moving fastest.
1 — b) neither ball is accelerated, and the upper ball is moving fastest.
1 — c) both balls are accelerated, and the lower ball is moving fastest.
d) the lower ball is accelerated, but the upper ball is not accelerated.
3 — e) neither ball is accelerated, and the lower ball is moving fastest.

Problem 6 (3 points):

A certain type of atom has only four energy levels, as shown in the figure. The "spectral lines" produced by the element are all visible, except for one ultraviolet (UV) line. The quantum jump that produces the UV line is *(hint: UV light is at a higher frequency than visible light)*

3 — a) state 2 to 1.
b) state 4 to 1
c) state 4 to 3
1 — d) state 1 to 4
e) impossible to determine without further information.

Problem 7 (3 points):

Which of the following provides evidence for the quantization of light?

a) the individual dots seen on a photographic plate when a photo is taken at extremely short exposure times.
b) interference effects seen when light passes through a narrow opening
c) both of the above.
d) experiments that spread light out into a spectrum of colors.
e) all of the above.

Problem 8 (3 points):

According to the Copenhagen view of quantum theory

a) nature is "non-local," i.e., instantaneously connected across a distance.
b) individual microscopic events are inherently unpredictable.
c) both of the above
d) the overall statistics of large numbers of microscopic events are inherently unpredictable.
e) all of the above.

Problem 9 (5 points, show your work):

You are hanging out with friends on the quad one clear night and see a spectacular meteor (a.k.a a`falling star') enter the atmosphere and burn up. With your handy-dandy, special wristwatch, you determine that the meteor was visible to you for exactly 2 seconds. In other words, the time it took for the meteor to enter the atmosphere and burn up was 2 seconds from your point of view. If you were an ant in a fireproof spacesuit riding on the meteor, how long would it have taken for the meteor to enter the atmosphere and burn up from your perspective? Assume the meteor travels at a constant speed of 0.98c during the event. *Ignore the effect of gravity on time.*

← Proper frame - clock moves with meteor

time dilation ⇒ Time is shortest in the Proper frame

$t = 2$ seconds at rest on ground

$\gamma t' = t$ ← you on quad

↑ Proper (meteor) frame

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

$$\gamma = \frac{1}{\sqrt{1-(.98)^2}} \simeq 5$$

$\gamma t' = t$ Time as Measured by Ant

$5t' = 2s$

$t' = \frac{2}{5}s = 0.4s$

Problem 10 (5 points, show your work):

According to the engineers, a particular airplane must be moving at 30 m/s in order to take off. Suppose this airplane starts from rest and has a constant acceleration of 5 m/s^2, how much time does it take for the plane to roll down the runway and achieve takeoff speed?

$a = \frac{\Delta v}{\Delta t}$ $\quad 5\ m/s^2 = \frac{30\ m/s - 0\ m/s}{\Delta t}$ $\quad \Delta t = \frac{30}{5} = 6$ seconds

Problem 11 (6 points, show your work):

The energy of a photon is 13 eV. If you were to look at this light as a wave rather than a particle, what is the wavelength of the light corresponding to this photon energy?

$E = h\nu \rightarrow \nu = E/h$ $\quad c = \lambda\nu \rightarrow \lambda = \frac{c}{\nu}$

$\lambda = \frac{ch}{E} = \frac{(3\times10^8\ m/s)(4.5\times10^{-15}\ eV\cdot s)}{13\ eV}$

$\lambda = 1\times10^{-7}$ Meters

Problem12 (5 pts):

Briefly explain – using concepts we have discussed in this course - why it is that if you watch a baseball game from a seat in the outfield part of the stadium you see the batter hit the ball around a second before you hear the crack of the bat.

Both sound (what you hear) and light (what you see) are wave phenomenon with finite speeds of propagation. Light moves at roughly 3×10^8 m/s while sound moves at ~330 m/s. So, from your perspective at a baseball game, the light that allows you to see the batter strike the ball arrives almost instantly while the sound takes takes almost a second to travel to your ears ... perhaps it is closer to ½ or ⅓ of a second in actuality depending on the location of your seat.

Problem 13 (5 pts, no need to show work):

A beam of blue light and a beam of red light are shown on a certain metal plate. A scientist determines that the the blue light causes electrons to be emitted by the metal while no electrons are emitted when the red light is shown on the plate. Briefly explain why this happens using concepts we have discussed in this course.

Blue light has a higher frequency than red light. Since the photon energy is given by $E = h\nu$, the photon energy for blue light is greater than that for red light. If the metal on which the light is shown requires more that the photon energy of red light but less than the photon energy of blue light to eject the electron, it would explain the observations.

Problem 14 (5 pts):

Please explain, using concepts from this course, why it is that in collisions between SUV's and small cars, the death rate for the occupants in the small cars is much higher than for the occupants of the SUVs. *(In formulating your answer, please ignore the effect of the differences in height of the vehicles even though it has a very real effect on the death rates. I'm looking for you to discuss another aspect of the collisions that leads to the death rate difference.)*

During the collision each object exerts the same force on the other according to Newton's third law (For every force, there is an equal and opposite force). Since $F = ma \Rightarrow M_{SUV} a_{SUV} = M_{small\ car} a_{small\ car}$

The Mass of the SUV is much larger than the mass of the small car. So the acceleration of the SUV (and the person inside the SUV) is much less, leading to less damage to persons inside the vehicle.

Problem 15 (6 pts):

Carbon-14 (^{14}C) undergoes radioactive beta decay (emitting an electron) with a half-life of roughly 5700 years. What nuclear species (isotope) results from this decay?

$$^{14}C \rightarrow e^- + {}^{14}N$$

Atomic number (# of protons) increases by 1

$n \rightarrow e^- + p$

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Problem 16 (6 pts): Clearly Answers to 16, 17 can vary . . .

Briefly defend the statement: "Science is very different from art."

Science is a methodology used to understand the world around us.. Art is not so constrained. Sometimes art is a product of the artist's attempts to understand the world and other times the motivation might come from another source such as a desire to share beauty or entertain. To the extent art is used to probe the human understanding of the universe it is NOT constrained by experiment as is science. Also art can be perceived differently by different people while every attempt is made to insure scientific observations/claims are seen/agreed to by everyone.

Problem 17 (6 pts):

Briefly defend the statement: "Science is very similar to art."

Often art is used as a way for humans to understand and share insights about the world around us, as is science. Also, science is a human endeavor. As such, it is subject to human bias, and human interpretation, as is art. Science may not be as open to interpretation as art, but it is hardly as black and white as it is typically portrayed. Scientists are drawn to formulate hypotheses, theories and interpretations that they perceive as aesthetically pleasing when possible. A scientist learns to judge the science of others in much the same way an artist might appreciate an artistic work. Often Scientists will describe scientific work using words you might consider more appropriately used by an artist . . . "elegant" or "crisp" or "beautiful" work.

hydrogen 1 H 1.0079																	helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 **	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	ununnium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
**Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

Some potentially useful formulas

$F = \frac{G m_1 m_2}{r^2}$ [m_1 and m_2 in kg, r in meters, F in Newtons] $\rightarrow G = 6.7 \times 10^{-11}$

$F = \frac{k q_1 q_2}{r^2}$ [q_1, q_2 in Coulombs, r in meters, F in Newtons] $\rightarrow k = 9 \times 10^{9}$

$F = ma$

(distance) = (speed)(time)

$v = \frac{\Delta x}{\Delta t}$

$a = \frac{\Delta v}{\Delta t}$

work = force x distance

Momentum = $p = mv$

$\Delta x' = \gamma \Delta x$, Δx longest in proper frame

$\Delta t' = \gamma \Delta t$, Δt shortest in proper frame

$\gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$

1 Joule = 1.6×10^{-19} eV

speed of sound = 330 M/s

$c = 3 \times 10^{8}$ M/s

$h = 6.6 \times 10^{-34}$ J.s or 4.5×10^{-15} eV·s

$\lambda = \frac{h}{p} = \frac{h}{mv}$

$v = \lambda \nu$

$\nu = \frac{1}{T}$ (T = period)

$E = h\nu$

$\Delta x \Delta p \geq h/2\pi$ $\Delta E \Delta t \geq h/2\pi$

$\frac{\Delta N}{\Delta t} = \lambda N$ $t_{1/2} = 0.693/\lambda$