Exam 2 (April 22, 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 In typical multi-electron atoms, the electrons all reside in the atom's lowest energy quantum state.
b) F If a sample of uranium-235 is subcritical, a nuclear explosion is imminent.
c) T According to quantum field theory, the gluon is the virtual particle (gauge boson) responsible for conveying the strong nuclear force.
d) F The force of gravity is many times stronger than the weak nuclear force.
e) F A typical chemical reaction involves changes in energy of millions of electron-volts.
f) T Water is a chemical compound.
g) F Carbon dioxide (CO_2) is an isotope of carbon monoxide (CO).
h) F According to quantum field theory, the Z particle is the virtual particle (gauge boson) responsible for conveying the strong nuclear force.
i) F According to quantum theory, the more precisely the position of an electron is determined the better known is the electrons velocity.
j) F The Higgs particle was discovered (first seen) in 2006.
k) F A chain reaction refers to the chemical processes that occur when hydrogen is mixed with oxygen and a match.
l) T or F The strong nuclear force is stronger than the electromagnetic force. — could argue either way depending on distance
m) F Nuclear fission is the energy source that powers stars.
n) F In quantum mechanics, the wave function specifies the exact position of a particle.
o) T Young stars are formed mostly of hydrogen.

Problem 2 (4 points):

A quantum state is

a) a term that refers to atoms that are able to emit photons.
b) a state that is smaller than most other states – for example, Rhode Island.
c) a phrase describing the frame of mind of a physicist who is contemplating the complicated aspects of matter.
4 - d) a reference to the potential spatial regions and energies allowed for particles according to quantum mechanics.
2 - e) the place where a particle is seen to be located.

Scores	
1.	30/30
2.	4/4
3.	4/4
4.	4/4
5.	4/4
6.	4/4
7.	4/4
8.	5/5
9.	6/6
10.	5/5
11.	10/10
12.	10/10
13.	10/10
Total	100/100

Wow!

Problem 3 (4 points):

You walk into a room that is contaminated with radioactive material. What factors are important in determining the potential danger to you of the radioactive material?

1 - a) the location of the material relative to you.
1 - b) the activity of the sample.
1 - c) the time you spend in the proximity of the sample.
1 - d) the type of radiation emitted by the sample.
4 - e) All of the above.

Problem 4 (4 points):

Which of the four fundamental forces binds the nucleus together, and which binds the atom [electron orbits] together?

2 - a) Strong nuclear force binds the nucleus, weak nuclear force binds the atom.
2 - b) Gravity binds the nucleus, electromagnetic force binds the atom.
c) Weak nuclear force binds the nucleus, strong nuclear force binds the atom.
d) Electromagnetic force binds the nucleus, strong nuclear force binds the atom.
4 - e) Strong nuclear force binds the nucleus, electromagnetic force binds the atom.

Problem 5 (4 points):

Quarks interact with other particles in nature via
1 - a) the strong nuclear force.
1 - b) the weak nuclear force.
1 - c) the electromagnetic force.
1 - d) gravitation.
4 - e) all of the above.

Problem 6 (4 points):

The source of energy for the creation of most gold atoms (a gold atom is heavier than an iron atom) used in jewelry is

1 - a) the gravitational collapse of a star.
b) a goldsmith's smelter.
c) The fission of a heavier element such as radium or hafnium.
4 - d) the shock wave of a supernova explosion at the end of the stellar life cycle for a large star.
e) the heat at the center of the earth.

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Problem 7 (4 points):

Carbon is

a) an element.
b) a chemical compound.
c) made up entirely of protons.
d) chemically inert (unreactive).
e) never found in stars.

Problem 8 (5 points):

A nuclear fusion process occurs and is described by the equation below. Determine and provide the unknown nucleus (symbolized by X) in the equation. ✓

$$^{7}Be + {}^{6}Li \longrightarrow X \rightarrow {}^{13}N$$

^{7}Be $Z=4 \to 4p, 3n$

^{6}Li $Z=3 \to 3p, 3n$

X has $7P, 6n \to {}^{13}N$

Problem 9 (6 points):

Suppose the nucleus below undergoes alpha decay, what is the nucleus left behind?

$$^{230}_{90}Th \longrightarrow \alpha + X \leftarrow {}^{226}_{88}Ra$$

X has $90-2=88$ protons $= Z$ ← Radium Ra

$= 22 - 4 \leftarrow 6 = A$

Would you expect this process to release energy or absorb energy?

This process Releases ~~E~~ energy

Problem 10 (5 points):

In the quark model of particle physics, is it possible to have a baryon with an electric charge of +2? If so, give a possible example. If not, why?

u c t $+2/3|e|$

d s b $-1/3$

|e| have qqq structure

uuu, ccc, uuc, ucc, uct, ttt etc. are all possible $q=+2$ baryons

Problem 11 (10 points):

Briefly describe the relationship between quantum uncertainty and radioactive decay.

Nuclear decay is a quantum process. This means we can quantify the probability that a nucleus will decay in a given time, but we can't determine when any particular nucleus will decay – that is, the decay time for the individual nucleus is completely uncertain. ← [Sufficient Ans. for full credit]

At a deeper level, the decay itself is a quantum process governed by quantum uncertainties. For example, the nonlocality of the α-particle wave function – say, extending outside a nucleus – leads to eventual α-decay, as there is a small but finite possibility the α is outside the nucleus. ← [I don't think we discussed this]

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Problem 12 (10 points):

The iodine isotope ^{131}I is a naturally radioactive nucleus that emits a beta (e-) with a half-life of 8 days. Because iodine is absorbed by the thyroid gland, people with malfunctioning thyroids can be treated medically by drinking a solution laced with ^{131}I. The radioactive iodine decays and causes tissue damage preferentially in the thyroid.

a) What nuclear isotope does the ^{131}I become when it decays?

$${}^{131}_{53}I \rightarrow e^- + {}^{131}_{54}Xe \; (+\bar{\nu}_e)$$

$${}^{131}_{54}Xe$$

b) If a sample of ^{131}I sitting on the hospital shelf has an activity of 200 decays per second today, how much time will pass before that activity drops to 25 decays per second? $\frac{\Delta N}{\Delta t}$

$t_{1/2} = 8$ days

In 8 days $\frac{\Delta N}{\Delta t}$ 50 →

100 $\Delta N/\Delta t$

$\Delta N/\Delta t$ → 25 ✓

24 days

Problem 13 (10 points):

In 1929, one of the big players in physics at the time, P.A.M. Dirac, said of quantum mechanics, "The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known …" Briefly defend or dispute Dirac's assertion that quantum mechanics explains chemistry.

defend

Quantum mechanics allows us to understand the energy levels and orbital shapes for electrons in atoms. Chemistry is a science concerned with interactions between atoms that involve rearrangements of the ~~The chemical behavi~~ electrons. or of The chemical behavior of each atom is governed by its electronic structure … which is, in principle understandable by quantum mechanics.

dispute

While the chemical behavior of atoms is dictated by their electronic structure, which can be understood through quantum mechanics, it is not practical to use quantum mechanics to calculate the behavior of large and complex systems. New phenomenon (such as life) arise with complexity that are not predictable and calculable by quantum mechanics.

Student does not need to defend and dispute statement for full credit.

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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]	unununium 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

$$F = \frac{G m_1 m_2}{r^2} \quad \begin{bmatrix} m_1 \text{ and } m_2 \text{ in kg} \\ r \text{ in meters} \\ F \text{ in Newtons} \end{bmatrix} \rightarrow G = 6.7\times10^{-11}$$

$$F = \frac{k q_1 q_2}{r^2} \quad \begin{bmatrix} q_1, q_2 \text{ in Coulombs} \\ r \text{ in meters} \\ F \text{ in Newtons} \end{bmatrix} \rightarrow k = 9\times10^{9}$$

$$F = ma$$

(distance) = (speed)(time)

1 Joule = 1.6×10^{-19} eV

Speed of Sound = 330 m/s

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

$$c = 3\times10^{8} \text{ m/s}$$

$$h = 6.6\times10^{-34} \text{ J·s}$$

or

$$4.5\times10^{-15} \text{ eV·s}$$

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

work = force × distance

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

Momentum = $p = mv$

$$v = \lambda \nu$$

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

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

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

$$E = h\nu$$

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

$$\Delta x \Delta p \geq \frac{h}{2\pi} \qquad \Delta E \Delta t \geq \frac{h}{2\pi}$$

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