Answers to polonium-210 questions

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First, please note my letter on page 2 in this issue, which corrects a point in my ^{210}Po article last month (February 2007, pages 1, 6). What follows here are the answers to the student activities that I posed in that article.

1. The decay equation is: $^{210}_{84}Po \rightarrow ^{206}_{82}Pb + ^{4}_{2}He$.

2. Yes, $^{206}_{82}Pb$ is stable. It constitutes 24.1% of natural lead.

3. This question was intended to encourage students to think about the reliability of information, whether in books or on the internet, and to consider how to decide what is reliable. Several sources point out that ^{210}Po is much more toxic than hydrogen cyanide, but two amazingly different ratios are given, 2.5 x 10^{11} and approximately 1 x 10^{6}. In round numbers, the former is almost a million-fold larger than the latter, which makes me think that a "mega" factor (10^{6}) has been overlooked in one of the calculations. I show here that the approximate factor of 1 x 10^{6} is the correct one.

   The 2.5 x 10^{11} factor is given in several editions of the CRC Handbook of Chemistry and Physics in the section on polonium in the history of the elements — on page B-32 of the 1982-83 edition and on page 4-24 of the 2002-03 edition. The CRC Handbook is normally a trustworthy source, but not in this case. In the same paragraph it says that 6.8 x 10^{-12} g is the "maximum permissible body burden for ingested polonium". This is the safe amount. Logically, then, 2.5 x 10^{11} x 6.8 x 10^{-12} g, or 1.7 g is a weight of HCN that is also safe.

   So what is the lethal dose of HCN? The Merck Index (11th edition, 1989), says the average fatal dose of HCN is 50-60 mg. The University of Oxford's MSDS sheet at *http://www.physchem.ox.ac.uk/MSDS/HY/hydrogen_cyanide.html*, gives <70 mg as the lowest published lethal dose for humans, and about 250 mg (based on mouse data) as the LD_{50} (the dose that is lethal for 50% of victims) for a 70-kg human. So the lethal dose is in the range of 50-250 mg of HCN, much less than the 1,700 mg that the CRC Handbook implies is safe! This internal contradiction makes it clear that the CRC Handbook has to be wrong about either the trillion-fold difference in toxicities or the safe dose of polonium.

   What about the internet? I googled on "polonium HCN" (January 2007). Most of the entries on the first page of hits say that ^{210}Po is 2.5 x 10^{11} times as toxic as HCN — quoting the CRC Handbook?? One of them, a BBC site, *www.bbc.co.uk/dna/h2g2/pda/A18446204?s_id=6*, quotes the trillion-fold factor on page 10; but on page 14 it says that as little as 0.1 microgram of ^{210}Po constitutes a lethal dose. If we take 100 mg as the average fatal dose of HCN, which is in the range noted above, then ^{210}Po is only about a million times more toxic than HCN on a weight basis — (100 x 10^{-3} g)/(0.1 x 10^{-6} g) = 1 x 10^{6}. So this source gives both values of the ratio!

   Several sources claim ^{210}Po is 1 x 10^{6} times more toxic than HCN. One is the University of Alabama media advisory at *http://images.main.uab.edu/emermed/POLONIUM%20210.doc*, which quotes *Ellenhorn's Medical Toxicology*, 2nd edition, 1997, page 1477. This site includes a short calculation of an LD_{50} value of 50 ng for ^{210}Po.

   Another is Wikipedia's entry for polonium on the internet (at *http://en.wikipedia.org/wiki/Polonium*). Under the heading "Acute effects", this article uses information from an Oak Ridge National Laboratory document in its reference 25, and from a U.S. Department of Energy document in its reference 24. From these data it calculates an LD_{50} value of 50 ng for ^{210}Po. Surely, these are trustworthy sources. Using 100 mg as the approximate lethal dose of HCN, the ratio of lethal doses, ^{210}Po/HCN, is (50 x 10^{-9} g)/(100 x 10^{-3} g) or 5 x 10^{-7}. This says that ^{210}Po is 2 million times more toxic than HCN on a mass basis. Again, it's a factor of approximately 1 x 10^{6}.

   Since this is not my field of expertise, I contacted an expert, Dave Whillans, who is a Senior Scientist in the Health Physics Department at Ontario Power Generation-Nuclear. He agrees that the lethal doses are more or less as given above, while pointing out that they can vary by several fold depending on the individual, on the extent of medical intervention, and whether one is talking about an LD_{50} value or a dose that is lethal for most anyone. Accordingly, the ratio of 1 x 10^{6} must be viewed as an order of magnitude value.

   But, why is the 2.5 x 10^{11}-fold factor so widely quoted? Since all the sources that give this large factor quote exactly the same value, I think they are all quoting each other or the CRC Handbook, which most persons would expect should be reliable — but isn't in this case. Considering the massive amount of information in it, one can't judge it too harshly if we find the occasional typo. Or is it a typo? One wonders where the 2.5 x 10^{11} factor came from.

4 $$k = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{138.39\ \text{d} \times 24\ \text{h d}^{-1} \times 3600\ \text{s h}^{-1}} = 5.80 \times 10^{-8}\ \text{s}^{-1}$$

5. I'll calculate this in two ways. You'll need a calculator that gives 10 significant digits if you use the first way.

Define: N_0 = the number of ^{210}Po atoms at time zero;
N = the number of atoms left after 1 second.
Then, N_0-N is the number of atoms that decay in 1 second. Incorporating the rate law for decay, we have

$$N_0 - N = N_0 - N_0(e^{-kt}) = N_0(1 - e^{-kt})$$
$$= N_0(1 - e^{-5.80\times10^{-8}\,s^{-1}\times 1\,s}) = N_0 \times 5.80 \times 10^{-8}$$

Since we are considering 1 g,

$$N_0 = \frac{1\,g}{210\,g\,mol^{-1}} \times 6.02 \times 10^{23}\ \text{atoms mol}^{-1}$$
$$= 2.87 \times 10^{21}\,\text{atoms}$$

Therefore, $N_0 - N = 2.87 \times 10^{21}\,\text{atoms} \times 5.80 \times 10^{-8}\,s^{-1}$
$$= 1.66 \times 10^{14}\ \text{atoms s}^{-1}$$

So, 1.66 x 10^{14} atoms decay in the first second in a sample that initially weighs 1 g.

You need a 10-digit calculator for the preceding calculation because N_0-N is the small difference between two very large and nearly equal numbers. A different approach, which avoids this problem, is to evaluate the initial rate by taking the first derivative of the integrated rate law.

$$-\left(\frac{dN}{dt}\right)_{t=0} = -\left[\frac{d}{dt}\left(N_0 e^{-kt}\right)\right]_{t=0} = -\left(N_0(-k)e^{-kt}\right)_{t=0} = +kN_0$$
$$= 5.80 \times 10^{-8}\,s^{-1} \times 2.87 \times 10^{21}\,\text{atoms}$$
$$= 1.66 \times 10^{14}\,\text{atoms/s}\ \ \text{(same as before)}$$

6. The energy released by a decay rate of 1.66 x 10^{14} atoms per second, which is the decay rate in 1 g of ^{210}Po, is given by

$$E = 1.66 \times 10^{14}\,\frac{\text{decays}}{s\ g} \times 5.3\,\frac{\text{MeV}}{\text{decay}} \times \frac{1.60 \times 10^{-13}\,J}{\text{MeV}}$$
$$= 141\ J\ s^{-1}\ g^{-1}$$

But, one watt (W) is, by definition, one joule per second. Therefore, ^{210}Po releases energy at the rate of about 140 W/g, as stated in the article. ■

Answers to *An intuitive crostic*

The winner of the book prize for solving the December crostic *An intuitive crostic,* is Dinie Steunenberg, Kelowna Secondary School, Kelowna BC. Dinie would also like to thank fellow teacher, David Lovering, for his crostic help. The quotation is taken from *The Natural Mind*, by Andrew Weil.

The history of science makes clear that the greatest advancements in man's understanding of the universe are made by intuitive leaps at the frontiers of knowledge not by intellectual walks along well-traveled paths.

A, Archimedes
B, neon
C, databanks
D, resistivity
E, eureka
F, wetting
G, work-up
H, emerald
I, idempotent
J, level off
K, that's that
L, hydrogen
M, elevenths
N, nucleons
O, agents
P, tantalate
Q, utterances
R, Rayleigh
S, affront
T, leans
U, microwaves
V, ill
W, nth
X, decibels ■

Su-chem-du with message

Another su-chem-du to keep your mind warm through the winter months. There is a message in the first row. Here is your clue: "what everyone is on March 17".

Everything else is the same as our usual su-chem-du. Each of the nine chemical symbols is to appear once in each row, column and each 3x3 square. At the bottom of the puzzle is the list of elements to be used. We'll draw the winner of a periodic table from the correct entries on May 7, 2007. Send your entry to *Chem 13 News,* March su-chem-du, Department of Chemistry, University of Waterloo, Waterloo ON N2L 3G1. Fax: 519-888-9168. E-mail: kjackson@uwaterloo.ca.

		Re			**Ir**			**H**
Ir			**I**		**S**		**O**	
	Er			**F**		**Ir**		
		Er			**O**			**S**
	V						**F**	
S			**H**			**Re**		
		F		**O**			**V**	
	Re		**S**		**Er**			**Ir**
V			**Re**			**S**		
Er	F	H	I	Ir	O	Re	S	V

Colleen Keaney wins su-chem-du

Colleen Keaney from Megan Murphy's class at Marymount Academy in Sudbury, Ontario was the winner of December's "su-chem-du with a message", page 6. Megan will receive a small version of the "most beautiful periodic table poster in the world". The answer to the clue "what one does while doing a su-chem-du in the winter" was "SiP HOT cHoCoLaTe" and can be found in the first row of the puzzle's solution, below.

Si	P	H	O	Tc	Ho	Co	La	Te
Co	Te	Ho	La	H	Si	Tc	O	P
La	Tc	O	Te	P	Co	Ho	H	Si
P	Ho	Co	Si	O	Te	H	Tc	La
Tc	O	Te	Co	La	H	Si	P	Ho
H	Si	La	Tc	Ho	P	O	Te	Co
Te	Co	Tc	P	Si	O	La	Ho	H
O	H	P	Ho	Co	La	Te	Si	Tc
Ho	La	Si	H	Te	Tc	P	Co	O