Teaching Nuclear Science in an Introductory Physics for the Life Sciences (IPLS) Course

John E Tansil Ph.D.
Department of Physics and Engineering Physics, Southeast Missouri State University, Cape Girardeau, MO, 63701, USA

Abstract

Nuclear science topics, traditionally relegated to the end of the textbook, are sometimes treated as "excess baggage" in an IPLS course. If teaching time grows short as the end of semester approaches, it is nuclear science that is dropped from the curriculum. We think this is a shortsighted approach and that textbook organization should take a backseat to the importance of nuclear science in an IPLS course. There are several reasons for teaching nuclear science: (1) increasing use of nuclear medicine (both diagnostic techniques and treatment), (2) renewed interest in nuclear power plants due to global warming concerns with burning of fossil fuels, and (3) concerns over terrorist's use of radioactive "dirty" bombs or small fission weapons. We have found that a Nuclear Data Table (aka Table of Isotopes) is very useful for presenting nuclear science topics and that two lab experiments on radioactive decay will suffice.

1

"Factoids" for an IPLS Course at Southeast Missouri State University

Course Name: PH121/021 Introductory Physics II (lecture & lab).
Four lectures and one 2-hour lab.

Topics Covered: Electricity, magnetism, optics, modern physics.

Prerequisites: College algebra and plane trigonometry.

Textbook: ***Physics*** (9th edition, John *Wiley & Sons, Inc, 2012)* *by Cutnell & Johnson.*

Lab Manual: ***Introductory Physics II Laboratory Manual (revised 2014)*** (15 lab experiments).

Homework: Approx 50 assignments from WileyPLUS (a web-based application that allows students to complete their homework online and receive instant feedback on their work.

Audience: Approx 50-70 students.
70% Life Science majors
30% Non-Life Science majors

2

What is the Audience in a "Typical" IPLS Course?

- Pre-Medical
- Pre-Optometry
- Pre-Pharmacy
- Pre-Dental
- Pre-Physical Therapy
- Pre-Veterinary
- Pre-Chiropractic

3

Why Teach Nuclear Science In an IPLS Course?

1. Nuclear science is ubiquitous in medical diagnostic techniques and treatment.
2. Renewed interest in nuclear power due to global warming concerns caused by burning fossil fuels.
3. Concerns over terrorist's use of radioactive "dirty" bombs or small fission bombs..

…. So the real answer is to create an informed citizenry!

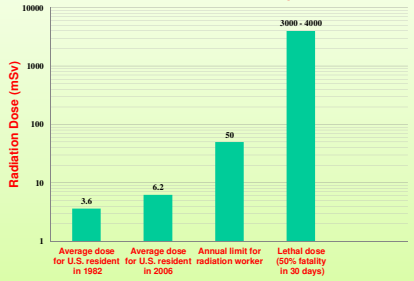
4

Nuclear Science Topics Whose Learning is Facilitated through the Use of a Nuclear Data Table

•Nuclear nomenclature	•Radioactivity
•Nuclear density	•Radioactive decay
•Isotopes & atomic masses	•Radioactive decay series
•Nuclear stability	•Biological effects of radiation
•Nuclear binding energy	

5

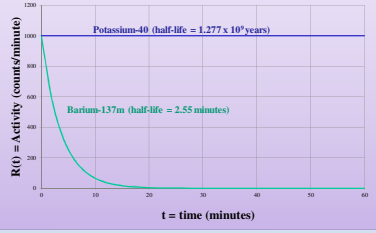
Radiation Dose for Different Populations



6

Lab Experiments in an IPLS Course

Much can be taught with Radiation Counting Experiments Using only Two Radioisotopes



7

Long-Lived Radioisotope:Potassium-40

•Many potassium compounds are available
•Natural abundance of K-40 is 0.0117%

8

Analyze Data to Obtain Half-Life of Long-Lived Radioisotope (Potassium-40)

Mass of KCl sample = 0.78 grams
Background activity R_{bg} = 134 cts /10 min
Total activity R_{tot} = 305 cts /10 min
Sample activity R_{sample} = 171 cts /10 min = 0.285 Bq

Whole-body activity $R = \frac{R_{sample}}{counting\ \ efficiency} = \frac{0.285}{0.015} = 19.0\ Bq$

$$\frac{\#\ of\ {}^{40}K\ atoms}{gram\ of\ KCl} = \left(\frac{\#\ of\ {}^{40}K\ atoms}{\#\ of\ K\ atoms}\right)\left(\frac{\#\ of\ K\ atoms}{molecule\ of\ KCl}\right)\left(\frac{\#\ of\ KCl\ molecules}{gram\ of\ KCl}\right) = 9.53 \times 10^{17}$$

N = Number of ${}^{40}K$ atoms in KCl sample = $(0.78)(9.53 \times 10^{17}) = 7.43 \times 10^{17}$

Decay constant $\lambda = \frac{R}{N} = \frac{19.0\ Bq}{7.43 \times 10^{17}\ atoms} = 2.56 \times 10^{-17}\ s^{-1}$

Half-life $T_{1/2} = \frac{\ln(2)}{\lambda} = \frac{\ln(2)}{2.56 \times 10^{-17}\ s^{-1}} = 2.71 \times 10^{16}\ s = 8.59 \times 10^{8}\ yr$

$$\%\ error = \frac{\left|1.28 \times 10^{9}\ yr - 8.59 \times 10^{8}\ yr\right|}{1.28 \times 10^{9}\ yr} \times 100\ \% = 32\ \%$$

9

Short-Lived Radioisotope: Ba-137m

Isotope Generator (cost approx. $250)

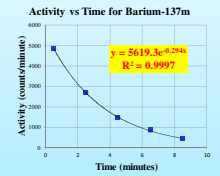
Mixture of Cs-137/Ba-137m (activity < 10μCi)

$$^{137}_{55}Cs \xrightarrow[30.1\ yr]{\beta^-} {}^{137m}_{56}Ba \xrightarrow[2.55\ min]{\gamma} {}^{137}_{56}Ba$$

10

Analyze Data to Obtain Half-Life of Short-Lived Radioisotope (Barium-137m)

Background Activity =	12	cts/min
Time	Sample + Background Activity	Sample Activity
(minutes)	(counts/minute)	(counts/minute)
0.5	4872	4860
2.5	2715	2703
4.5	1475	1463
6.5	862	850
8.5	469	457



$$T_{1/2} = \frac{\ln(2)}{\lambda} = \frac{\ln(2)}{0.294\ min^{-1}} = 2.36\ min$$

$$\%\ error = \frac{\left|2.55\ min - 2.36\ min\right|}{2.55\ min} \times 100\ \% = 7.5\ \%$$

11