Lesson 14

Radiotracers
Introduction

• **Basic principle:** All isotopes of a given element will behave identically in most physical, environmental and biological environments.

• Easier to detect radioactive atoms than stable atoms.

• Simple

• Cheap

• Amazing breadth of applications. Now part of the standard arsenal of analytical techniques.
Designing a Radiotracer Experiment

• Radioactive isotopes of a given element behave the same as stable isotopes.

• Isotope Effect--Most concern for H, 15% effect for $^{12}\text{C}$ vs $^{14}\text{C}$.

• Nonisotopic tracers
Intermolecular vs Intramolecular Effects

- Intramolecular--decarboxylation of malonic acid ($\text{HOO}^{14}\text{C}^{12}\text{CH}_2^{12}\text{COOH}$)
- Intermolecular--decarboxylation of benzoic acid--7--$^{14}\text{C}$ ($\text{C}_6\text{H}_5^{14}\text{COOH}$ vs $\text{C}_6\text{H}_5^{12}\text{COOH}$)
Basic Principle #2

- Radioactivity does not change the chemical and physical properties of the system.
- Tracer activities, bond strengths, energy of emitted radiation
- $^3$H problem
- “Daughter atom problems”
Basic Principle #3

- No deviation from normal physiological state.
- Injecting stable as well as radioactive material
Basic Principle #4

- Chemical and physical form of the labeled material is the same as the unlabeled material.
- Aqueous chemistry
- Adsorption, carriers, carrier-tracer exchange
- Radiochemical purity
- Position of the label
Basic Principle #5

• Label stays intact
Practical Considerations

• Availability of tracer
• $t_{1/2}$
• Labeling, position of the label
• Ease of detection
• Health and safety aspects
• Waste disposal
Calculation of the amount of tracer needed

- No excuse for turning a tracer experiment into a detection problem.
- Statistics (> $10^4$ cts)
- Counting efficiency, detector type, geometry factors, chemical yields
- Safety factor
Hazard evaluation

- Dose rates, RBEs
- Effects on physiology
- Waste problems
- Green chemistry
Radiotracer Preparation

Commonly Used Tracers

<table>
<thead>
<tr>
<th>Tracer</th>
<th>Type</th>
<th>Half-Life (yr)</th>
<th>Decay Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3$H(T)</td>
<td>R</td>
<td>12.33</td>
<td>$\beta^-$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>$^{14}$C</td>
<td>R</td>
<td>5730</td>
<td>$\beta^-$ 0.156</td>
</tr>
<tr>
<td>$^{22}$Na</td>
<td>C</td>
<td>2.60</td>
<td>$\beta^+, \gamma$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.274</td>
<td></td>
</tr>
<tr>
<td>$^{24}$Na</td>
<td>R</td>
<td>15.0</td>
<td>$\gamma$ 1.369</td>
</tr>
<tr>
<td>$^{32}$P</td>
<td>R</td>
<td>14.3</td>
<td>$\beta^-$ 1.71</td>
</tr>
</tbody>
</table>

- n-rich vs p-rich
- PET nuclides
Labeling

• Position: acetic-1-\(^{14}\)C acid = \(\text{CH}_3^{14}\text{COOH}\), acetic-2-\(^{14}\)C acid = \(^{14}\text{CH}_3\text{COOH}\)

• Terms: Specifically labeled, U, N G
Methods of labeling

- Chemical synthesis, best except for chirality
- Biological synthesis, tedious
- Tritium
- Commercial supplier problems
Physical tracers

- Wear, corrosion
- Mixing
- Fluid motion
- Pollutant tracing
- Measuring unknown volume

\[ V = V_i \left( \frac{A_1}{A_2} - 1 \right) \]
Chemical Applications

- Test separation procedures
- $K_{sp}$ measurements
- Exchange reactions
- Chemical reaction mechanisms
Example

• Cyclization of $\omega$-phenoxyacetophenone to 2-phenylbenzofuran
Physical Isotope Effects

- Gaseous diffusion
- Distillation
Chemical Isotope Effects

\[ AX + BX^* \rightleftharpoons AX^* + BX \]

Table 4-2 Typical Equilibrium Isotope Effects

<table>
<thead>
<tr>
<th>Reacting System</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H^2H(g) + H_2O(l) \rightleftharpoons H_2(g) + ^2HOH(l) )</td>
<td>3.2</td>
</tr>
<tr>
<td>( ^{14}CO_2(g) + ^{12}COCl_2(g) \rightleftharpoons ^{14}COCl_2(g) + ^{12}CO_2(g) )</td>
<td>1.0884</td>
</tr>
<tr>
<td>( [\text{Co(NH}_3)_4^{12}\text{CO}_3]^{+} + ^{14}\text{CO}_3^{2-} \rightleftharpoons ^{12}\text{CO}_3^{2-} + [\text{Co(NH}_3)_4^{14}\text{CO}_3]^{+} )</td>
<td>0.8933</td>
</tr>
</tbody>
</table>
Kinetic Isotope Effects

\[ A + B \rightarrow AB \rightarrow \text{products} \]

\[ \frac{d[B]}{dt} = k[A]^a[B]^b \]

\[ \frac{d[B^*]}{dt} = k^* [A]^a[B^*][B]^{b-1} \]

\[ \frac{d[B]}{d[B^*]} = \frac{k[B]}{k^* [B^*]} \]

\[ \log_{10}\left( \frac{S_y}{S_0} \right) = \left( \frac{k^*}{k} - 1 \right) \log_{10}(1 - \gamma) \]
Biological applications

 Autoradiography
DNA Analysis
Radioimmunoassay

Labeled antigen $\text{Ag}^*$ (F) + specific antibody Ab + unlabeled antigen $\text{Ag}^+$ results in labeled antigen-antibody complex $\text{Ag}^*\text{-Ab}$ (B) and unlabeled antigen-antibody complex $\text{Ag}\text{-Ab}$. 
Figure 19. The radioimmunoassay technique to measure hormone levels in the body involves mixing natural hormones (from a blood sample) and radioactively prepared hormones together, and adding that mixture to a solution containing artificially produced antibodies. The two hormones compete for binding sites on the antibodies. The hormones attach to the antibodies in amounts that are proportional to their concentration.
Environmental Applications of Radiotracers

- Used in tracing pollutant motion in atmosphere, hydrosphere, lithosphere

Advantages of radiotracers

- Not influenced by state of system
- Highly penetrating
- Good detection sensitivity
- If $t_{1/2}$ short, will disappear after expt.
- Cheap

BIG PROBLEM--HP
Typical Environmental Radiotracers

- $^{41}\text{Ar}$
- $^{24}\text{Na}$
- $^{82}\text{Br}$
- $^{140}\text{La}$
# Industrial Uses of Radiotracers

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Application</th>
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</table>
| $^3\text{H}$ | Self-luminous aircraft and exit signs  
Luminous dials, gauges, wrist watches  
Luminous paint |
| $^{24}\text{Na}$ | Location of pipeline leaks  
Oil well studies |
| $^{46}\text{Sc}$ | Oil exploration tracer |
| $^{55}\text{Fe}$ | Analysis of electroplating solutions  
Defense power source |
| $^{60}\text{Co}$ | Surgical instrument and medicine sterilization  
Safety and reliability of oil burners |
| $^{63}\text{Ni}$ | Detection of explosives  
Voltage regulators and current surge protectors  
Heat power source |
Nuclear Medicine

• Therapy and diagnosis

• Most important radionuclides are $^{99}$Tc$^{m}$ and the I isotopes. Over 90% of procedures involve these nuclei
$^{99}\text{Tc}^{m}$

- 143 keV gamma rays
- 6 hr $t_{1/2}$
- Use of generators
$^{99}\text{Mo} \xrightarrow{\beta^-} ^{99}\text{Tc}^m \xrightarrow{\gamma} ^{99}\text{Tc}$
PET, Positron Emission Tomography
ANTERIOR INFARCTION TREATED WITH TPA
Isotope Dilution Analysis

- **Direct IDA**

  - In direct IDA, we are faced with the problem of determining the amount of some inactive material \( A \) in a system. Let us define this unknown amount as \( x \) grams. To the system containing \( x \) grams of inactive \( A \), we add \( y \) grams of active material \( A^* \) of known activity \( D \). Thus we know the specific activity of the added active material, \( S_1 \).

\[
S_1 = \frac{D}{y}
\]

After thoroughly mixing the active material \( A^* \) with the inactive \( A \) in the system, one isolates, not necessarily quantitatively, and purifies a sample of the mixture of \( A \) and \( A^* \) and measures its specific activity, \( S_2 \).

\[
S_2 = \frac{D}{x + y}
\]

\[
S_2 = \frac{D}{x + \frac{D}{S_1}}
\]

\[
x = \frac{D}{S_2} - \frac{D}{S_1} = \frac{D}{S_1} \left( \frac{S_1}{S_2} - 1 \right) = y \left( \frac{S_1}{S_2} - 1 \right)
\]