Please understand that with material flows all calculations are back of the envelope (aka estimates).

**Problem 1**
With the project of Yucca mountain the US is hoping to store nuclear waste that is currently stored onsite at the nuclear facilities. What if all this waste was thrown into the ocean. How would the concentration of uranium in the ocean change if we assume 100% of the waste is Uranium. Go online and find the US nuclear waste from 1968 onwards (hint: EIA). Use Klee & Graedel to calculate the current concentration of Uranium in the ocean. You must also know the volume of the oceans. Calculate the increase in the concentration of Uranium (in percentage) if all the US waste is dumped into the ocean.

**Solution to P1:**

**Step 1: Find Uranium Quantities**
Using the EIA: [http://www.eia.doe.gov/cneaf/nuclear/spent_fuel/ussnfddata.html](http://www.eia.doe.gov/cneaf/nuclear/spent_fuel/ussnfddata.html)

We know the spent fuel amounts to 47,023 metric tonnes of Uranium.

**Step 2: Find actual conc. of U in the oceans**
From Klee&Graedel we find that the concentration of Uranium in seawater is 0.003 g/Mg.

**Step 3: Find Volume and Weight of the oceans**
An approximation of the volume of the oceans is $1.35 \times 10^9$ km$^3$

Density of seawater = 1030 kg/m$^3$

Thus mass of the oceans =

$$1030 \text{ kg/m}^3 \times 1.35 \times 10^9 \text{ km}^3 \times \frac{1 \times 10^9 \text{ m}^3}{1 \text{ km}^3} = 1.39 \times 10^{21} \text{ kg or } 1.39 \times 10^{18} \text{ Mg}$$

**Step 4: actual vs predicted U**
Actual amount of Uranium in oceans = 0.003 g/Mg $\times 1.38 \times 10^{18}$ Mg = $4.14 \times 10^{15}$ g of U

Actual + waste = $4.14 \times 10^{15}$ g + \(47,023 \text{ tons} \times \frac{1 \times 10^6 \text{ g}}{1 \text{ tonne}}\) = $4.14005 \times 10^{15}$ g

**Answer:**
An increase of 0.001%
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All this assumes that the Uranium spreads evenly across the oceans. Also if the uranium is reprocessed (recycled) the waste goes down to 3% of the original amount, so the increase in the concentration would be much smaller.


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**Problem 2**

Let's assume we just opened a mega-factory or conglomerate of factories that emits 8 Gtonnes of carbon (C) into the atmosphere in a given year. In that year how much will the CO₂ concentration change.

**Solution to P2:**

**Method A**:

1. **Step 1: calculate CO₂ emissions by weight**
   - The atomic weight of carbon is 12.01
   - The atomic weight of CO₂ is 44.01

   Thus 8 Gtonnes of carbon = \( \frac{44.01}{12.01} \times 8 \) or 29.3 Gtons of CO₂

2. **Step 2: calculate amount of CO₂ in the atmosphere.**
   - CO₂ conc → 380 ppmv or 0.038% by volume or 0.057% by weight
   - → about \( 2.94 \times 10^{12} \) tons in total.

3. **Step 5: amount after mega factory**

   \[
   \text{Answer:} \quad 2.94 \times 10^{15} \text{ kg} + (29.3 \text{ Gtonnes} \times \frac{1 \times 10^{12} \text{ kg}}{1 \text{ Gtonne}}) = 2.9693 \times 10^{15} \text{ kg or 0.9% increase}
   \]

**Method B (alternative way):**

1. **Step 1: Calculate actual carbon present in the atmosphere**
   - Think of the atmosphere as a system with CO₂. The rate our is the rate at which plants and the oceans absorb CO₂. If you have the residence time you can back-calculate to find the amount in the reservoir.

   From class: \( \text{residence time} = \frac{\text{amount in reservoir}}{\text{rate out}} \)

   Residence time for CO₂ ≈ 10 years (given in class slides)

   Rate out = Gross Primary productivity of trees and oceans
   \( \text{GPP plants} = 120 \text{ Gtonnes of Carbon/year (from IPCC diagram of NPP)} \)
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GPP oceans = \( \frac{3}{7} \times 120 \) Gtonnes of C/year (this is just a rough estimate, we didn’t talk about GPP for the oceans but we know that oceans sequester ~30% of the CO\(_2\) according to Wackernagel. Alternatively, you could ignore the oceans and still get an order of magnitude result)

Rate Out = 171.4 Gtonnes of C/year

Amount in reservoir = rate out * residence time = 1,714 Gtonnes of C (in CO\(_2\) form)

Step 2 – calculate the increase in the conc. due to the 8 Gtonne emission of carbon.

\[
\frac{8}{1714} \times 100\% = 0.47\% \text{ increase}
\]

**Answer:** 0.47% increase

---

Problem 3
Assume you smoke 20 cigarettes/day for a year. How much lead are you exposed to?

**Hint:** If you can’t find the concentration of lead in tobacco, assume the whole cigarette is average biomass.

**Solution to P3:**

**Step 1: Concentration of Lead in Tobacco**


Lead Concentration: 8-10 \( \mu \)g/g (~9 \( \mu \)g/g)

From: [http://www.irdes.fr/ecosante/OCDE/813010.html](http://www.irdes.fr/ecosante/OCDE/813010.html)

The weight of the tobacco in one cigarette is 0.65 - 1 gram (for simplicity use one gram)

Thus one cigarette entails an exposure of 9 \( \mu \)g/cigarette

B) If you didn’t find the above use Klee and Graedel

Average Concentration of Lead in dry plant = 2.7 g/Mg or 2.7 \( \mu \)g/g

Thus one cigarette = 2.7 \( \mu \)g of lead

**Step 2: Calculate total lead with a 365 day-year**

Cigarettes per year = 365 x 20 = 7300

**Answer:**

**Method A:**

Lead exposure in a year = 7300 cigarettes x 9 \( \mu \)g/cigarette = 65,700 \( \mu \)g or 0.065 grams

**Method B:**
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Lead exposure in a year = 7300 cigarettes \times 2.7 \mu g/cigarette = 19,710 \mu g or 0.019 grams

Problem 4
Using the composition of the human body provided below, estimate the world mobilization due to human bodies of the top 10 elements in the body.

![Human Body Composition Table]

Mass of the element assumes an average body mass of 150 pounds (68.04 kilograms). Source: Geigy Scientific Tables, Ciba-Geigy Limited, Basle, Switzerland, 1984
Solution to P4:

Assuming there is 6.5 billion people in a given time span.

<table>
<thead>
<tr>
<th>Element</th>
<th>Conc. in Body (kg)</th>
<th>Mobilization (metric tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>44.2</td>
<td>2.87E+08</td>
</tr>
<tr>
<td>Carbon</td>
<td>12.2</td>
<td>7.93E+07</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>6.8</td>
<td>4.42E+07</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>2</td>
<td>1.30E+07</td>
</tr>
<tr>
<td>Calcium</td>
<td>1</td>
<td>6.50E+06</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.68</td>
<td>4.42E+06</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.17</td>
<td>1.11E+06</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.136</td>
<td>8.84E+05</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.102</td>
<td>6.63E+05</td>
</tr>
<tr>
<td>Sodium</td>
<td>0.102</td>
<td>6.63E+05</td>
</tr>
</tbody>
</table>

Problem 5
If we expect population to increase to 9 billion in 50 years from now, and GDP per capita to increase by a factor of 7, how much will we need to reduce our environmental impact per GDP just to stay even?

Solution to P5

Note the IPAT equation in differential form is only valid for infinitesimals

\[
\frac{dI}{dt} = \frac{dP}{dt} + \frac{dA}{dt} + \frac{dT}{dt}
\]

You calculate “yearly rates” by taking into account compounding effects:
Ex: Future Amount = Present Amount x (1+ r)^time

Population
9 billion = 6.5 billion * (1 + r_P)^50
r_P = 0.653%

Affluence
7 = 1 * (1 + r_A)^50
r_A = 3.969%

So what happens to Technology?

For the impact to stay constant r_A + r_P + r_T = 0

Thus r_T = -4.622%
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\[ T_{\text{future}} = T_{\text{present}}(1-0.04622)^{50} = 0.0938 \]

**Answer:**  
\[ T_{\text{present}} \text{ must reduce by a factor of around 11 (or 1/0.0938)} \]

**Problem 6**  
If the future value \( F \) of an asset with a present value \( P \) is increased at the (interest) rate \( i \) per time period, then over \( n \) time periods, show that \( F = P(1 + in) \) for \( i^2 \ll 1 \).

**Solution to P6**  
\[ F = P (1+i)^n \]

Using the binomial series expansion  
\[ (1 + i)^n = 1 + ni + \frac{n(n - 1)i^2}{2!} + \frac{n(n - 1)(n - 2)i^3}{3!} \]

Since \( i \ll 1, i^2 \) and higher terms \( \sim 0 \).  
And \( (1 + i)^n = 1 + ni \) so  
\[ F = P(1 + in) \text{ for } i^2 \ll 1 \text{ QED} \]

**Problem 7**  
Using the TRI (it is okay to report the answers in pounds):  

A) In 1998 in Louisiana, how much chromium has emitted to air?  

Solution: 10,757 pounds

B) In 2001, in the U.S. what was the total on and off site disposal (and other releases) of HAP’s?  

Solution: 2,699 million pounds

C) In 2002, in Middlesex, NJ which chemical had the largest emitted quantities on and off site (disposal + other releases)? Hint: you can either find it or export it (fancy) into excel and use the sort tool.

Solution: Zinc Compounds