SOLUTIONS MANUAL FOR
NANOTECHNOLOGY
Understanding Small Systems
THIRD EDITION

by

Ben Rogers
Jesse Adams
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CHAPTER 1 HOMEWORK

1.1) What is the definition of nanotechnology?

Nanotechnology is the control of matter measuring between 0.1 to 1000 nanometers. It means engineering things at the atomic, molecular and macromolecular scales.

1.2) The number 1,234,567 written out is one million, two hundred thirty four thousand, five hundred sixty seven. Write out this number: 1,200,300,400,500,600,700,800,901

One septillion, two hundred sextillion, three hundred quintillion, four hundred quadrillion, five hundred trillion, six hundred billion, seven hundred million, eight hundred thousand, nine hundred and one

1.3) Rank the following things from largest to smallest: polio virus, drop of water, mercury atom, e coli bacterium, helium atom, human red blood cell.

Drop of water, human red blood cell, e coli bacterium, polio virus, mercury atom, helium atom

1.4) The concept of the atom was introduced approximately how long ago?

2,500 years ago

1.5) What are the three main components of an atom?

protons, neutrons, and electrons

1.6) What are the main components of an atom's nucleus?

neutrons and protons

1.7) What is the Law of Definite Proportions?

In a pure compound, the elements combine in definite proportions to each other

1.8) What is the Law of Multiple Proportions?

Elements combine in the ratio of small whole numbers. (For example carbon and oxygen react to form CO or CO_2, but not $CO_{2.3}$.)

1.9) Boyle's law states that $PV=C$, where P is the pressure of a gas, V is the volume and C is a constant (assuming constant temperature). Consider a gas held in a 4 m^3 container at 1 kPa. The volume is then slowly doubled. (a) What is the new pressure? (b) Use atoms to explain how a larger container leads to a lower pressure.

ANSWER

A) ½ of the original pressure = **0.5 kPa**

B) The pressure is nothing more than the individual gas molecules colliding over and over again with the container walls, exerting a force per unit area. If you make the volume of a container larger, the molecules' collisions with the wall will occur less frequently. This means that the pressure will decrease.

1.10) (a) What is the mass of a square piece of aluminum foil 100 micrometers thick and 10 centimeters wide (aluminum = 2.7 g/cm^3). (b) How many atoms are in the piece of foil (aluminum=27 g/mol)?

ANSWER

A) 2.7 g/cm^3 = 2,700 kg/m^3

$(100\times10^{-6}\ \text{m})(10\times10^{-2}\ \text{m})(10\times10^{-2}\ \text{m})(2700\ \text{kg/m}^3)$ = 0.0027 kg = **2.7 g**

B) N = (2.7 g)(6.02×10^{23} atoms/mol)/(27 g/mol) = **6.023×10^{22} atoms**

1.11) Calculate the mass of an atom of (a) hydrogen (1.0 g/mol); (b) silver (107.87 g/mol); (c) silicon (28.09 g/mol).

ANSWER

A) $\dfrac{1.0\ \text{g/mol}}{N_A} = 1.66\times10^{-24}\ \text{g}$

B) $\dfrac{107.87\ \text{g/mol}}{N_A} = 1.79\times10^{-22}\ \text{g}$

C) $\dfrac{28.09\ \text{g/mol}}{N_A} = 4.66\times10^{-23}\ \text{g}$

1.12) What are the mass ratios of the elements in these chemical compounds? (a) Ammonia, NH_3; (b) Ethanol, C_2H_6O; c) Toluene, C_7H_8. (Note: nitrogen=14 g/mol; hydrogen 1 g/mol; carbon=12 g/mol; oxygen=16 g/mol).

ANSWER

A) Mass of nitrogen = (1 mol)(14 g/mol) = 14 g

Mass of hydrogen = (3 mol)(1 g/mol) = 3 g

Ratio: 4.7 parts nitrogen, 1 part hydrogen

B) Mass of carbon = (2 mol)(12 g/mol) = 24 g

Mass of hydrogen = (6 mol)(1 g/mol) = 6 g

Mass of oxygen = (1 mol)(16 g/mol) = 16 g

Ratio: 4 parts carbon, 2.7 parts oxygen, 1 part hydrogen

C) Mass of carbon = (7 mol)(12 g/mol) = 84 g

Mass of hydrogen = (8 mol)(1 g/mol) = 8 g

Ratio: 10.5 parts carbon, 1 part hydrogen

1.13) What now famous talk did Feynman give to stimulate development in nanotechnology? What year did he give it?

There's Plenty of Room at the Bottom, 1959

1.14) What less optimistic topic did some of those in the audience suspect was meant by the title of Feynman's talk?

The number of unwanted, open jobs in physics

1.15) Many computers use one byte (8 bits) of data for each letter of the alphabet. There are 44 million words in the Encyclopaedia Britannica. (a) What is the bit density (bits/in^2) of the head of a pin if the entire encyclopedia is printed on it? Assume the average word is 5 letters long. (b) What is the byte density? (c) What's the area of a single bit in nm^2? (d) A CD-ROM disk has a storage density of 46 megabytes/in^2 and a

DVD disk has a storage density of 329 megabytes/in^2. Is the pinhead better or worse than these two storage media? How much better or worse?

ANSWER

A) Area of pin head = 0.00307 in^2

bits = (44,000,000 words)(5 letters/word)(8 bits/letter) = 1760000000 bits

Bit density = 5.7329×10^{11} bits/in^2

B) Byte density = (5.7329E+11 bits/sq inch)/(8 bits/byte) = **7.17×10^{10} bytes/in^2, or about 72 GB/in^2**

C) 1 in^2 = 6.4516×10^{14} nm^2

(6.4516×10^{14} nm^2/in^2) / (5.7329×10^{11} bits/in^2) = **1125 nm^2**

D) About 1560 times better than the CD-ROM and 220 times better than the DVD.

1.16) What is meant by “gray goo?”

A nightmarish scenario where self-assembling nano-bots or nano-elements proliferate out of control, turning the world to an amorphous goo.

1.17) For a gray goo scenario to play out, what entirely new type of machine would be necessary?

Self-assembler

1.18) What year was the word ‘nanotechnology’ first used?

1974

1.19) A baseball is made up of trillions of trillions of atoms. (a) Write out the number for one trillion trillion. (b) NASA estimates that there are about 10^{21} stars in the universe. Is this number higher or lower than the number of atoms in a baseball?

ANSWER

A) 1,000,000,000,000,000,000,000,000

B) There are about 1,000 times fewer stars.

1.20) The distance between the nuclei of two iron atoms is about 4 Angstroms (1 Angstrom=10^{-10} m). (a) How many nanometers is that? (b) How many iron atoms on this spacing would it take to reach 2 microns (1 micron=10^{-6} m)?

A) 0.4 nm; B) 5,000 atoms

1.21) What five categories are the most popular areas for nanotechnology patents in the U.S.? **dendrimers, quantum dots, carbon nanotubes, fullerenes and nanowires**

SHORT ANSWER

1.22) Name three things you are familiar with (easy for you, personally, to identify with) that are roughly 1 mm in size. Name something that's about 1 micrometer in size. Name something that's 1 nanometer in size.

1.23) Based on your education and interests, describe the role you might be best suited to play in the multidisciplinary arena of nanotechnology.

1.24) Perform your own topic search using an internet search engine. Use the same search terms as Figure 1.7, and reconstruct the chart. How have the results changed and what does this suggest?

1.25) Make a list of at least five name brand products that incorporate nanotechnology.

1.26) Search Science Magazine's online table of contents. Find the percentage of issues from the previous year with at least one article whose title contains the prefix 'nano.'

1.27) The concept of the atom was ridiculed by Romans; the idea that he earth revolved around the sun was initially shunned as well. What scientific ideas are at the heart of controversy these days? What are the implications of these ideas? Which groups are at odds? How much is proven about the idea and how much is conjecture?

WRITING ASSIGNMENTS

1.28) Nanotechnology is multidisciplinary; it draws from, and requires expertise in, numerous scientific and engineering fields. So the question becomes: Is there such a thing as nanotechnology? Are there any applications, research fronts, concepts, or overarching goals which are unique to nanotechnology and not just an advancement in another field (chemistry, physics, medicine, biology, etc.)? Or is nanotechnology really just the name for where all these other fields overlap? Citing and quoting evidence from credible sources (including at least two that are non-technical in nature such as a newspaper article, a book review, or a governmental document) and those more geared toward scientists and engineers (for example, an editorial or an article from a scientific journal or a speech from a convention) take one side of this issue and argue it in 500 words. It would also certainly be worth interviewing an expert on the topic (a professor or government official perhaps).

1.29) Technological progress in nuclear power and biotechnology has been thwarted to a degree by public distrust, misinformation and resistance to change. There are very real dangers and ethical issues involved in such technological progress, and at the same time, very real advantages. How is nanotechnology similar? How is it different? What lessons can be taken from the manner in which nuclear power and biotechnology are understood by the general public to make for a safer, more productive transition period in the case of nanotechnology?

1.30) Richard Feynman thought that the atomic hypothesis was the best single sentence to summarize all of scientific knowledge. Write your own sentence at the top of a page and use the rest of the page to convince the reader your choice makes sense.

<u>CHAPTER 2 HOMEWORK</u>

2.1) Give at least four advantages of miniaturization in machine design.

<u>**less material used in production, multifunctionality, compactness, lighter weight, improved strength-to-weight ratio, easier storage (both for manufacturers and consumers)**</u>

2.2) True or false: Miniaturization improves the factor of safety of a product.

<u>False</u>—while this is true in certain cases, it is not always true.

2.3) Scaling laws are: (a) general engineering guidelines for miniaturization, (b) useful for estimating how the characteristics of something will vary with changes in characteristic dimension, (c) helpful estimates of a device's performance at the nanoscale (d) accurate predictors of physical characteristics at the macro-, micro- and nanoscales.

<u>B</u>—useful for estimating how the characteristics of something will vary with changes in characteristic dimension

2.4) Scaling laws derive from: (a) design engineers' experience, (b) market demands, (c) the laws of physics, (d) the material used.

<u>C</u>—the laws of physics

2.5) The characteristic dimension is: (a) the dimension in which an object is largest in a three-dimensional representation of that object, (b) metric units, (c) a representative measurement of something for comparison purposes, (d) a variable used to determine the surface-to-volume ratio of an object.

C—a representative measurement of something for comparison purposes

2.6) True or false: the characteristic dimension, *D*, of an object is the average of that object's width, height and length.

False—while width, height or length can be used for *D*, this metric is not typically an average

2.7) Based on the scaling laws, how many times greater is the strength-to-weight ratio of a nanotube (*D*=10 nm) than the leg of a flea (*D*=100 μm)? Than the leg of an elephant (*D*=2 m)?

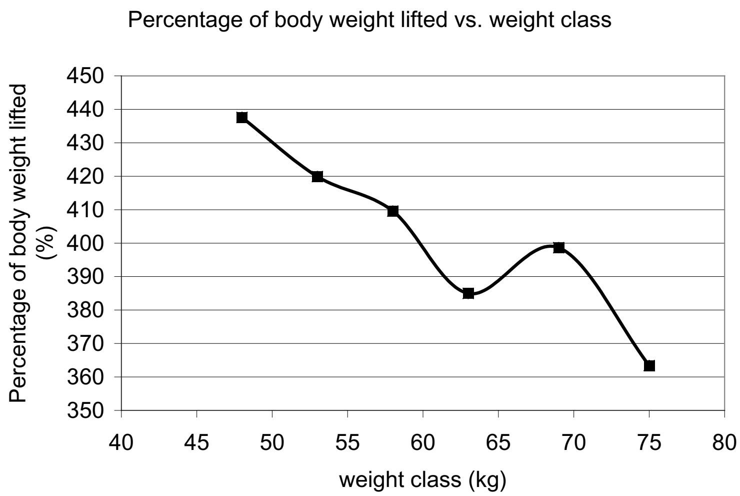
For the flea, S/W=1/100E-6=10000; for the nanotube, 1/10E-9=1E8; for the elephant, 1/2= 0.5. So the strength-to-weight ratio of the nanotube is 10,000 times better than the flea's leg and 2E8 times better than the elephant's leg.

2.8) Data from the 2004 Olympic Games in Athens, Greece are provided in Table 2.2. Plot the percentage of body weight lifted versus weight class. Is the same trend evident in the women's weightlifting event as the men's event shown in Figure 2.4? In what weight class is there a discrepancy and how might this be explained?

ANSWER

Convert lbs to kg, then divide lift weight by weight class for percentage of body weight lifted.

WOMEN'S GOLD MEDAL WINNERS			
Weight class (kg)	Lift (lbs)	**Lift (kg)**	**PERCENTAGE**
48	463.05	**210**	**438**
53	490.61	**223**	**420**
58	523.69	**238**	**410**
63	534.71	**243**	**385**
69	606.38	**275**	**399**
75	600.86	**273**	**363**



<u>There is a discrepancy in the 69 kg weight class that might be explained by a weak showing in that particular category during that Olympic games. Data from world *records*, where each category reflects the best showing ever, more closely follow the trend.</u>