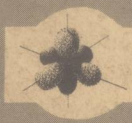
60.7%

5.2 X 10-1

Molecular Weight Calculations

10^8

6.1 g



PROGRAMMED UNIT IN CHEMISTRY

POWELL

.75
.25

$$\frac{48.0 \text{ amu}}{100 \text{ amu}} \times 100\% = 48\%$$

PRENTICE-HALL, INC.

1.0 amu
35.5 amu
36.5 amu

$$\frac{50 \text{ g}}{65.4 \text{ g/g-atoms}} = 0.76 \text{ g-atoms}$$

Programmed Unit in Chemistry

MOLECULAR WEIGHT CALCULATIONS

by

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Objectives for this Unit

This unit will help you learn certain mathematical relationships which are fundamental to chemistry.

It is assumed that you can give from memory the names and symbols of common elements. You should know the meaning and significance of atomic weight and atomic number. You should be able to determine the atomic weight of common elements from a Periodic Table.

You should be able to write the names and formulas of many compounds with the aid of a Reference Table. You should be able to predict whether a compound is primarily ionic or covalent in nature.

Instructions to the Student

Programmed instruction is a method of helping you learn better and more easily. You proceed in small steps, check yourself at each step, make few errors, and work at your own speed. The form of programmed instruction may make it look like a test, but this is not a test. This is a method of teaching yourself. You will not be graded on the responses you make while learning. However, you will be held responsible for mastery of the content of this unit at a later time.

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In addition to a Periodic Table and this program, you need a sheet of paper, a pen, an uncluttered desk, and a slide rule, if you use one. Later you will need your notebook. Your instructor will tell you whether to write your response in the book or on a separate sheet of paper. The sheet may also be used for scratch work. Place the answer sheet at the bar, so it will cover the rest of the page.

CALCULATING FORMULA WEIGHT, SIGNIFICANT FIGURES

Instructions to the Student

In all chemical calculations there are two important considerations. One is the units; the other, significant figures. Units are the most important part of any calculation. They describe the physical and mathematical relationships which exist. Units tell what is related and how these things are related. The numbers simply indicate how much is involved.

---

1. In the expression 10 miles per hour, the units are _____ and _____. The numbers are _____ and _____.

---

miles hour 10 1 (understood)

2. If your answer is correct, slide the answer sheet to the next bar. If you were in error, read the item again. Draw a line through the incorrect response, and write the correct response several times.

On your answer sheet write the units of each of the following expressions:

17 grams _____

---

grams

3. 27.5 ml _____

---

ml

4. 32.0 grams/mole _____

---

grams/mole

5. 0.87 cal/g _____

---

cal/g

6. 16.0 amu _____

amu

7. Show all units at every step of a calculation. They provide a built-in check on the method. Let us take as an example the simple arithmetic problem "If an automobile travels at an average rate of 40 mph, how far does it travel in 45 minutes?"

$$\begin{aligned} \text{Distance} &= \text{rate} \times \text{time} \\ D &= R \times T \\ D &= \frac{40 \text{ miles}}{1 \cancel{\text{hr}}} \times \frac{1 \cancel{\text{hr}}}{60 \cancel{\text{min.}}} \times 45 \cancel{\text{min.}} \\ D &= 30 \text{ miles} \end{aligned}$$

Miles are units of distance and the answer is correct. If by carelessness you simply combine some numbers, such as $40 \times \frac{60}{45}$, and then tag miles onto the numerical answer, you will come up with a ridiculous answer.

If you make the same calculation but with the units shown at each step,

$$\frac{40 \text{ miles}}{1 \text{ hr}} \times \frac{60 \cancel{\text{min.}}}{1 \text{ hr}} \times \frac{1}{45 \cancel{\text{min.}}}$$

the answer will come out in units of miles/hr^2. Common sense tells you these units are not units of distance.

"A solution contains 0.10 grams of salt in each ml of solution. If 12.5 ml of solution are evaporated to dryness, what weight of salt remains in the evaporating dish?" Work out this problem on your answer sheet, then check the steps below. Show units with each and every step. _____

$\frac{0.10 \text{ g}}{1 \cancel{\text{ml}}} \times 12.5 \cancel{\text{ml}} = 1.25 \text{ g}$ (Grams are units of weight and the problem asks, "what weight?")

8. A problem is not worked satisfactorily unless units are used at each step, even though you may arrive at a correct numerical answer. A correct method is at least as important as the correct answer.

In the previous problem 1.25 g is the correct answer in terms of units but not in terms of significant figures.

By definition, significant figures are numbers which express the result of a measurement such that only the last digit is in doubt. If a number has 4 significant figures, there are 4 digits in the number. The first 3 are known exactly, the 4th is doubtful, and by definition there are 4 significant numbers.

In the next five probelms, indicate how many significant figures there are in the number and what the doubtful figure is.

In 167 there are ____ significant figures and the number ____ is doubtful.

---

3 s. f. 7 is doubtful

9. In 1264 there are ____ significant figures and the number _____ is doubtful.

---

4 s. f. 4 is doubtful

10. 3927 _____ _____

---

4 s. f. 7 is doubtful

11. 69 _____ _____

---

2 s. f. 9 is doubtful

12. 96,438 _____ _____

---

5 s. f. 8 is doubtful

13. Significant figures are concerned with the number of digits (exact and doubtful) in a number, not with the number of decimal places.

123, 12.3 and 0.123 all contain the same number of significant figures. The number of significant figures is _____, and in each case the _____is doubtful.

---

3 3

14. In the next problem you are given a group of numbers. One of the numbers has a different number of significant figures from all the rest. Select this number and write it on your answer sheet. How many significant figures are there in each of the other numbers?

18 63 127 46 _____ _____

127 does not belong with the group because it has 3 significant figures. All the other numbers have 2 significant figures.

15. 16.2 2.734 621 0.962

_____ does not belong with the others because all the rest have _____ significant figures.

2.743 3 s. f.

16. 84.1 73 246 1.87 _____ _____

73 3 s. f.

17. 12.17 9461 6.2 476.3 _____ _____

6.2 4 s. f.

18. 64 0.12 0.6 6.6 _____ _____

0.6 2 s. f.

19. Zero is significant or not, depending upon where it occurs in the number.

Rule I: If it occurs within the number (not the first or last digit) it is always significant.

Example: Zero is significant in 607, 19.06, 104.3.
Both zeros are significant in 10.601.

Rule II: Zero as the first digit or digits in a number is never significant. Its function as the first digit or digits is to locate the decimal point.

In these examples, the underlined zero or zeros are not significant. They locate the decimal point. 0.62 .07 0.063 .0064 0.601

In the examples above, how many s. f. are there in each number?

_____ _____ _____ _____ _____

2 1 2 2 3

20. For each of the next five items, answer the following questions:

(1) How may significant figures are there?
(2) If the number contains a zero or zeros, are they significant? (apply the rules)
(3) Why is the zero significant?

Example: 106.7 has 4 significant figures. The "0" $\frac{\text{is}}{\text{(is/is not)}}$ significant because it occurs within the number.

Answer the questions for 1206.3 _____ _____ _____

---

5 s. f. is significant occurs within the number

21. 70.632 _____ _____ _____

---

5 s. f. is significant occurs within the number

22. 0.62 _____ _____ _____

---

2 s. f. is not significant locates decimal point

23. 602 _____ _____ _____

---

3 s. f. is significant occurs within the number

24. 0.07603 _____ _____ _____

---

4 s. f. (The first 2 zeros are not significant, they locate the decimal point. The 3rd zero is significant because it occurs within the number.)

25. The only problem left is whether zero is significant as the final digit in a number.

Rule III: If the zero is the final digit, and follows the decimal point, the zero is significant. Otherwise there is no reason for it to be there.

17.70	contains	4 significant figures
73.0	contains	3 significant figures
6.020	contains	4 significant figures
0.70	contains	2 significant figures
17.0900	contains	6 significant figures

Rule IV: If zero is the final digit or digits and precedes the decimal point, you cannot decide whether its function is to locate the decimal point or whether it is the result of measurement. Exponential notation, which we will not develop here, is required. So that you will not be reduced to guessing, we will state arbitarily for our purposes that zero as a final digit or digits preceding the decimal point is significant.

Example: In 170 the zero is significant. In 60,200 all the zeros are significant.

The four rules for zero as a significant figure, thus condense to the statement that zero is a significant figure except at the beginning of a number. Now go back to the beginning of the program and summarize in your notebook the important points about units and significant figures. When you return to this point, practice what you have learned on some additional examples.

How many significant figures are there in 16.730? _____

---

5 the s. f. are underlined 16.730

26. In 0.071 _____

---

2 0.071

27. In 17,063.12 _____

---

7 17,063.12

28. 6270 _____

---

4 6270

29. 709.00 _____

---

5 709.00

30. 0.0690 _____

---

3 0.0690

31. 22.4 _____

---

3 22.4

32. Why do you need to know how many significant figures a number has?

You need to know how many significant figures there are in numbers involved in calculations so that you can tell what degree of accuracy is warranted in your answer.

The result of a calculation can be no more precise than the least accurate measurement involved in the calculation.

You may know that one measurement of length is 673.21 inches (5 significant figures). You have been able to measure another length, 10.5 inches, only to 3 significant figures. If you subtract

673.21 inches	5 s.f.
10.5 inches	3 s.f.
662.71 inches	

You are justified in reporting your answer only to 3 significant figures or as 663 inches. (3 s.f.)

Another example. You are able to measure the length of a block of wood as 4.62 cm and the width as 9.3 cm. What is the area?

4.62 cm	3 s.f.
9.3 cm	2 s.f.
1386	
4158	
42.966 cm^2	

5 figures are not justified. The least accurate measurement contains only 2 significant figures, so the answer is 43 cm^2.

If the number following the last significant figure is 5 or more, increase the last significant figure by 1.

One final refinement. Certain numbers by definition are exact numbers. For instance the density of water at 4° C is 1 g/ml. The 1 is defined as 1.00000 g to as many places as necessary. Thus in calculation, such as 17.9 ml × 1 g/ml = 17.9 g, the limiting number of significant figures is _____.

---

3 (in 17.9 ml)

33. When we talk of 2 atoms or 3 molecules, the 2 and 3 are exact numbers. They have as many significant figures as you need.

You should apply these conventions about units and significant figures in all chemical calculations.

Refer now to the problem in item 7. How should the answer be reported?_____ Why? _____

1.3 g (The least accurate measurement, 0.10 g, is to 2 s. f., therefore the answer is only justified to 2 s. f. (not 2 decimal places). 1.25 g is rounded to 1.3 g. In all your succeeding work, check units and significant figures.)

If this is your first experience with significant figures, you may find this enough new material for one session. You may find it useful to invent some additional problems for yourself and return to this program at a later time.

34. In order to compare the atomic weight or atomic mass of one element with the atomic mass of another element, you need a reference standard. The actual masses are minute and cumbersome. In 1961 the International Commission on Atomic Weights selected C^{12} as the reference standard. The following material is based on this standard. If the Periodic Table you are using is different from this standard, your numerical answers may be slightly different, but the principles are the same.

The atomic masses of all elements are now compared to the isotope of the element, _____ , which weighs_____atomic mass units.

C 12

35. Elements heavier than carbon have masses_____ than 12.

---

greater, higher (or some such expression)

36. Elements lighter than carbon have atomic masses less than_____.
(number)

12

37. Now make use of your Periodic Table. Consult the key to locate the atomic weight or atomic mass, not the atomic number. You should express answers in the following work to 3 significant figures.

From the Table, the atomic mass of barium, Ba, is 137.34 amu. Written as 3 s. f., the atomic weight of Ba is_____.

---

137 amu

38. Fluorine's atomic mass is 18.9984 amu. This number has_____ significant figures.

6

39. Fluorine's atomic mass, rounded to 3 significant figures is _____ amu.

19.0

40. The element whose mass is approximately twice that of C is _____.
(name and symbol)

---

magnesium Mg

41. Its atomic mass to 3 significant figures is_____.

24.3 amu

42. You notice that atomic mass and atomic weight are used interchangeably. However, molecular weight and formula weight should not be used interchangeably. Molecular weight should be applied only to those substances that form by covalent bonding. Substances whose bonds are primarily ionic, are said to have formula weights.

You would thus refer to the _____ of NH_3.
(molecular weight/formula weight)

---

molecular weight

43. You calculate the _____ of K_2CO_3.
(molecular weight/formula weight)

---

formula weight

44. Calculating the molecular weight or formula weight of any substance is a simple process of arithmetic based on the axiom that "The whole is equal to the sum of its parts." If you know how many atoms of each element are required you can simply total the weights.

Problem: Calculate the molecular weight of hydrogen chloride. Report your answer in amu and to three significant figures.

The formula for hydrogen chloride is _____ .

HCl

45. The formula, HCl, shows that hydrogen chloride contains _____ atom of hydrogen combined with 1 atom of _____.

---

1 chlorine

46. Round the atomic masses to 3 significant figures before calculations, and report your final answer to only 3 s. f. From the Periodic Table determine that the relative mass of H is _____ amu. The relative mass of Cl is _____amu.

1.01 35.453 or 35.5

47. To 3 s. f. the mass of 1 H is 1.01 amu; the mass of 1 Cl is 35.5. (The 4th s. f. in 35.453 is 5; therefore, to 3 s. f., the mass of 1 Cl is 35.5) The molecular weight of HCl (1 H = 1.01 amu and 1 Cl = 35.5 amu), is _____ _____.

36.5 amu (3 significant figures)

48. In referring to sodium chloride, we use the term formula weight because the bonding in sodium chloride is _____.
(covalent/ionic)

---

ionic

49. The formula weight of sodium chloride is calculated in a similar fashion. The formula is_____.

NaCl

50. The relative mass of_____Na atom is_____.

---

1 23.0 amu

51. The relative mass of one Cl atom is_____.

35.5 amu

52. The formula weight of NaCl is_____amu.

58.5 amu

53. Calculate the formula weight of calcium oxide. The formula for calcium oxide is_____.

CaO

54. CaO contains 1 Ca atom weighing_____ and 1 O atom weighing _____. The formula weight is_____.

(Ca) 40.1 amu + (O) 16.0 amu = 56.1 amu

55. The formula weight of magnesium sulfide is_____.

MgS (Mg) 24.3 amu + (S) 32.1 amu = (MgS) 56.4 amu

56. Calculate, to 3 significant figures, the molecular weight of water. The formula for water is_____.

H_2O

57. H_2O contains_____atoms of hydrogen.

2

58. Each H atom has a relative mass of _____ amu.

1.01 amu

59. Two H atoms therefore weigh 2 × 1.01 amu or _____. H_2O contains_____atom(s) of oxygen with a relative mass of _____.

2.02 amu 1 16.0 amu

60. The total weight of 2 H atoms and 1 O atom is _____ + _____ = _____.

2.02 amu + 16.0 amu = 18.0 amu

61. The molecular weight of water, 18.0 amu, is the_____of the weights of the individual atoms.

---

sum (total)

62. In order to calculate the molecular weight or formula weight of any substance you need to know the _____for that substance.

---

formula

63. From the formula you can tell the number and kinds of elements in the substance. You also need a Periodic Table so you can determine the relative masses of the_____.

---

elements

64. From the formula and the relative masses of the elements, you can calculate the_____or _____weight.

---

molecular formula (either order)

65. Calculate the _____ of calcium chloride.
(molecular wt/formula wt)

---

formula weight

66. Its formula is _____.

$CaCl_2$

67. Its formula weight is _____.

---

1 Ca = 40.1 2 Cl = 2 × 35.5 = 71.0 71.0 + 40.1 = 111 amu (3 s. f.)

68. Calculate the formula weight of sulfuric acid, H_2SO_4. _____

---

2 H = 2 × 1.01 = 2.02
S = 1 × 32.1 = 32.1
4 O = 4 × 16.0 = 64.0
98.12 or 98.1 amu

69. To calculate the formula weight of copper (II) sulfate, you first need to know its formula, _____. The formula weight is _____ amu.

$CuSO_4$ Cu = 63.5 amu
S = 32.1 amu
4 O = 4 × 16.0 64.0 amu
159.6 amu 3 s. f. = 160 amu

70. The formula for cupric nitrate is _____.

$Cu(NO_3)_2$

71. This indicates that cupric nitrate contains _____ atom of copper, _____ atoms of nitrogen, and _____ atoms of oxygen.

---

72. Remember that a subscript following the parenthesis affects everything within the parentheses. The formula weight of cupric nitrate is _____.

---

1 Cu = 63.5 amu
2 N = 2 × 14.0 = 28.0 amu
6 O = 6 × 16.0 = 96.0 amu
187.5 amu or 188 amu

73. Calculate the formula weight of ammonium phosphate. Its formula is _____.

$(NH_4)_3PO_4$

74. Its formula weight to 3 significant figures is _____.

---

3 N = 3 × 14.0 = 42.0
12 H = 12 × 1.01 = 12.12
1 P = 1 × 31.0 = 31.0
4 O = 4 × 16.0 = 64.0
149.12 or 149 amu

75. The molecular weight of sulfur trioxide is _____.

SO_3 1 S = 32.1
3 O = 3 × 16.0 = 48.0
80.1 amu

76. The formula for manganese dioxide is _____ and its formula weight is _____ amu.

MnO_2 Mn = 54.9
2 O = 2 × 16.0 = 32.0
86.9 amu

77. There is only one further variation. Certain salts build water molecules into their crystals. Such water is called water of hydration, or water of crystallization. Blue copper (II) sulfate is an example.

Blue copper sulfate has the formula $CuSO_4 \cdot 5\ H_2O$. This is read as copper (II) sulfur sulfate with 5 molecules of water of hydration. The dot stands for "with" and is not the · used in algebra to indicate multiplication. The formula weight is the sum of the weight of the copper (II) sulfate and the 5 molecules of water. You may refer to previous answers in order to calculate that the formula weight of $CuSO_4 \cdot 5\ H_2O$ is_____.

$CuSO_4$ = 160 amu Formula weight = 250 amu
$5\ H_2O = 5 \times 18.0 =$ 90 amu

78. The formula for barium chloride with 2 molecules of water of crystallization is_____.

$BaCl_2 \cdot 2\ H_2O$

79. Its formula weight is _____.

Ba = 137.0
$2\ Cl = 2 \times 35.5 =$ 71.0
$2\ H_2O = 2 \times 18.0 =$ 36.0
244.0 or 244 amu

80. The useful household cleaner called "washing soda" is chemically sodium carbonate with 10 molecules of water of crystallization. Its formula weight to 3 significant figures is_____.

$Na_2CO_3 \cdot 10\ H_2O$
$2\ Na = 2 \times 23.0 =$ 46.0
C = 12.0
$3\ O = 3 \times 16.0 =$ 48.0
$10\ H_2O = 10 \times 18.0 =$ 180.0
286.0 or 286 amu

81. You now understand the principle and practice of calculating formula or molecular weights. Copy the following questions in your notebook and write your answers following the question in your own words.

(1) When do we use the term molecular weight, and when do we use the term formula weight?

(2) What is the general principle by which we calculate molecular or formula weight?

(3) What information and what reference material do we need?