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ABSTRACT

Twenty-one modules from ALCHEM, a computer-assisted instruction program, are presented. ALCHEM consists of a set of modular programs which are used at Simon Fraser University to cover some basic concepts introduced in an introductory college-level general chemistry course. The interactive exercises do not furnish background information or introduce new material, but serve to help students to become more aware of the meaning of basic chemical concepts, their interrelationships, and their applicability to practical situations. Although ALCHEM is available as a course by itself, its main use is as a depository for computer-assisted instructional (CAI) modules which are copies onto other CAI programs designed for specific chemistry courses. Material developed prior to July 1973 was in the Coursewriter III language; future material will be written in York/APL. (Author/OB)

ALCHEM

exercises in basic chemical concepts

a computer-assisted
instruction program
for general chemistry

Coursewriter III version
Instructor's Manual

July, 1973

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SFU

ALCHEM consists of a set of modular programs covering some of the basic concepts introduced in the first year of a college-level general chemistry course. Much of the material can also be used at the secondary school level.

As with any c.a.i. course, it is important that both instructors and students have a clear understanding of what ALCHEM can and cannot do. In particular, we would emphasize that this course is not intended to furnish an a priori introduction to the material, nor is it an effective means of communicating background information to the student. In other words, ALCHEM is <u>not</u> in competition with the textbook! Our principal object has been the creation of a highly interactive series of exercises that will help the student become more aware of the meaning of basic chemical concepts, their application to practical situations, and the inter-relations between them. In attempting to keep the dialogue as fast-moving and interactive as possible, only the barest essentials of theory are presented in the program. ALCHEM is perhaps best used after the student has already been exposed to the material by some other means (lectures, reading, audiotapes, etc.), but before he is given numerical problems to solve.

At Simon Fraser University, ALCHEM is available as a "stand-alone" course in which students are permitted to access any module in any order. Its main use, however, is simply as a depository for c.a.i. modules which are copied into other c.a.i. courses designed for specific Chemistry courses offered by the University. Thus the c.a.i. course "c101" supports the regular <u>Chemistry 101</u> course, and the ALCHEM modules contained therein (together with other c.a.i. material) is sequenced according to the "week number" in which it is required, and also is indexed according to the specific learning objectives to which each module relates.

The various modules in ALCHEM were developed during the period 1970-73. Development of further material for this Coursewriter III version of ALCHEM ceased in July 1973. All further ALCHEM material will be written in York/APL, as modified by SFU for c.a.i. use.

mod 01
EXPONENTIAL NOTATION

The student is first asked if he has any knowledge of scientific notation. If he does, and is able to demonstrate this knowledge in several simple problems, then he is branched around most of the material and can exit quite rapidly. All students are checked out on "computer notation", i.e. the convention of expressing quantities in the forms "6.02 x 10**23" and "6.02 E23".

Students demonstrating less familiarily with the subject are led through simple powers of 10 and then to combinations of these powers with decimal factors. Finally, they are required to convert between various decimal and exponential expressions.

At the present time, exponential arithmetic is not covered in this module. The separate c.a.i. course MATHOP offers a much more detailed introduction to exponential notation and arithmetic, and is more suitable for those who have had no previous training in this area.

mod 02
USE OF THE CALC FUNCTION

CALC is a user-written Coursewriter function that permits the terminal to be used as a "desk calculator" any time the system is ready to receive a student response. Typing the word "calc" followed by the appropriate expression has the effect of temporarily removing the student from "c.a.i. mode"; the arithmetic expression is evaluated by the CALC program, and the answer is returned to the terminal. After the answer has been printed, the system is again ready to receive an input from the student.

This module is intended to familiarize the student with the use of this function; the use of CALC is encouraged in later modules to remove the drudgery of doing arithmetic and to generally speed things up.

Emphasis is placed on multiplication and division, with passing attention given to addition and subtraction, powers, roots, and logarithms.

mod 03

SIGNIFICANT FIGURES

A brief treatment of significant figures, emphasizing the dual role of zero as a significant figure and as a place locator. More material on this subject is found in Problem 1-1 of CHEMEX. The present material was adapted from a course authored by S. Marcus of Ohio State University.

mod 04

UNIT CONVERSION FACTORS

The concept is introduced by demonstrating the interconversion of "inches" and "feet". The student sets up similar factors for other simple conversions: inches-cm, ergs-calories, liters-grams (using density as the conversion factor). Finally, there is a brief exercise on more complex conversions.

mod 05

INTERPRETATION OF GRAPHS

This module was also adapted from Ohio State University material. Within the admittedly narrow constraints of the typewriter terminal, it introduces the concepts of delta-Y, delta-X, and slope. The student determines these quantities from a graph that is typed out; he then finds the intercept and obtains the equation of the line. He is finally given some data to plot, and the accuracy of his plotting and interpretation is checked.

mod 06

WEIGHT-WEIGHT RELATIONS, CONSERVATION OF MASS

No knowledge of chemical equations or formulas is required here. The student is presented with a "word reaction" describing the oxidation of magnesium metal, and is asked to select a weight of magnesium to be burned. The program calculates the weight of product obtained, and the student finds the weight of oxygen required by difference. The program then reduceds the amount of metal by half, and leads the student to see that the amount of product obtained will be proportional to the weight of magnesium consumed. The problem is then repeated, but with excess oxygen present, thus introducing the concept of a limiting reactant.

After this the student is presented with an arbitrary weight of magnesium, generated by a random function on the system. He calculates the mass of product obtained, and is then asked to find the weight-percent of Mg in the oxide from the weight data. Finally, he finds the percent composition of strontium oxide from a given weight ratio of strontium to oxygen, and determines the relative combining weights of the two elements.

mod 07

LAW OF MULTIPLE PROPORTIONS

The student is given weight data for oxidations of copper leading to the (I) and (II) oxides. He is then led through the procedure for finding which oxide contains the greater amount of oxygen per unit weight of copper. He is shown how the assumption of a given formula for the one oxide determines the formula of the other.

mod 08

RELATIVE WEIGHTS AND ATOMIC WEIGHTS

The magnesium oxidation reaction is used again to show how the concept of relative weights can be applied. A more complex case, that of H2 + O2, is presented, and the student is shown how the relative weight assigned to hydrogen depends on our assuming a given formula for water.

mod 09
THE MOLE CONCEPT

The student is led gradually from the idea of atomic weight, through "weight of N-moles", to "weight of 1 atom" and "weight of N-atoms". The numerical parameters in several of the problems are generated randomly on each execution of the program, and the actual problems picked are also determined randomly, so students can repeat this unit with minimum "repetition".

mod10
BALANCING SIMPLE EQUATIONS

The difference between a subscript and a coefficient (which, admittedly, does not show up very well on a typewriter!) is delineated, and the student counts the total number of atoms in an expression such as "2O3". This leads to a simple equation involving O2 and O3. Exercises based on two other simple equations are presented. Finally, an equation representing the combustion of butane is balanced several times, following a different sequence in each instance.

mod11
FORMULA AND MOLECULAR WEIGHTS

This module begins with review exercises on atomic weights and "weights of atoms". The student calculates several formula weights, and uses them to find the number of moles present in a given mass of material, the mass of a given number of moles, and the mass of an individual molecule.

mod12
NAMES AND SYMBOLS OF THE ELEMENTS

This is a drill exercise covering 38 elements. The student is presented with the name of the element, and must enter its symbol. In addition, and at the student's option, the program will select a symbol, and the student must enter the name of the element, correctly spelled. A system function recognizes phonetically equivalent, but incorrect spellings.

The drill items are selected at random from a list. If the student's initial response is correct, that particular item is deleted from the list. Otherwise, it is retained and will be presented again. Thus the student is ultimately left with a residuum of the more difficult items, which are presented more and more frequently until he has "learned" them.

mod 15

EMPIRICAL FORMULAS FROM WEIGHT DATA

Finding mole ratios in binary compounds from weight data in simple combination reactions. Use of percent composition data to obtain empirical formulas of CO and Pb_3O_4.

mod 18

ELECTRONS IN ATOMS: QUANTUM NUMBERS

The principal quantum number- n; the quantum numbers l and m, and their permissable values. Orbital ("s-p-d-f") notation. Possible orbitals for various values of n, number of electrons in the various orbita

mod 19

ELECTRONS IN ATOMS: ELECTRON CONFIGURATIONS OF ATOMS

Principal quantum number n and potential energy of the electron. Aufbau principle and electron configurations of the elements; the first 13 elements in detail, and the general building up of the Periodic Table.

mod 20

THE NUCLEUS: ISOTOPES, ATOMIC MASS, ATOMIC NUMBER

The proton and neutron as nuclear building blocks. Isotopes and nuclides. Mass number, atomic number, and neutron number.

mod 21

RELATIVE WEIGHTS OF ATOMS AND THE ATOMIC WEIGHT SCALE

Calculation of the mass ratios of atoms from their actual masses. Mass ratio of an atom to carbon. Relative weights of atoms on the C=12.00 scale. The atomic mass unit, and its use in converting atomic weights into weights of atoms. Comparison of equal masses and equal numbers of atoms of different atomic weights. Relative (atomic) weight data from simple chemical reactions.

EXAMPLES OF ALCHEM DIALOGUES

The examples found on the following pages are intended to give course instructors and teachers a general idea of the scope of coverage and level of treatment of the various topics comprising ALCHEM. Very little attempt has been made to demonstrate the various branching possibilities in the program, treatment of anticipated and unanticipated wrong answers, alternate forms of correct answers, etc. In any event, these details change from month to month (and even, at times, from day to day!); the only "up to date" record of ALCHEM is what exists "on disk" at a given moment. Course printouts are available to those who want them.

ALCHEM is written in Coursewriter III, Version 2, an IBM Program Product supported by 360/370 systems. A number of user-written functions are required in ALCHEM, and several system modifications are recommended. External users can obtain information on these matters from the CAI Centre, Simon Fraser University.

ALCHEM
mod 01

EXPONENTIAL NOTATION

BIG ONES AND LITTLE ONES

The scale of the world extends far beyond what we can count on our ten fingers; chemistry, in common with other sciences, is replete with very large and very small numbers. For example:

A good sized (1 gm) diamond contains 50,150,000,000,000,000,000,000 atoms of carbon (give or take a few).

Each of those atoms weighs 0.000 000 000 000 000 000 000 019 94 gram.

By using EXPONENTIAL NOTATION, we can conveniently work with and express all these numbers, and still let our ten fingers do some of the work. Are you familiar with exponential notation? (Yes or no, please.)

***** no

Well, let's look at exponential notation in a little more detail. Does the expression "ten to the fourth power" mean anything to you - like, do you know its value?

***** 10,000

Exactly! Do you know how to express "ten to the fourth power" on the typewriter?

***** 10**4

Just to check you out on this a bit more, please enter an integer between 2 and 9.

***** 4

Okay, what is the value of 10**4 ?

***** 10,000

Good! Now what is 10**8 as a number?

***** 100,000,000

And finally, please express "10,000,000,000" as a power of 10.

***** 10**9

No, your exponent is wrong; please try again.

***** 10**10

Very good!
Now in scientific work, we rarely get nice round numbers like this. More commonly, we get such things as "31,400". Notice, however, that this number can be expressed as a product of two quantities: (coefficient) x (power of 10)
3.14 x 10000 = 3.14 x 10**4 = 31,400
Notice that the power, 4, is just the number of places to the RIGHT that the decimal point in the coefficient 3.14 must be moved in order to make 31400.
Now this same quantity can also be expressed using 10**3 as a factor; How would you do this?

***** 31.4x10**3

Very good!
Now, let's get back to powers of 10 for a minute. 10**1 has what value?

***** 10

Correct; any number, raised to the first power, is just the same number unchanged.
Now, how about "10**0" - what is its value?

***** 1

Right you are! Again, any quantity raised to the "zeroth" power is unity.
And finally, what is the value of 10**-1?

***** 0.1

Very good! When a number is raised to a negative power, the appropriate value is written in the denominator, so we have a fraction.
How would you express the quantity "1/10,000" as a power of 10?

***** 10**-4

Now see if you can express 0.442 as an exponential number, using 10**-1 as the exponent?

***** 4.42x10**-1

Very good.

USE OF THE C.A.I. "CALC" FUNCTION

A QUICK TRIP THRU CALC
In subsequent parts of this course we will be throwing lot's of (easy!) problems your way- it's the only way to really learn chemistry, unfortunately. But to save you time, you are encouraged to make use of the CALC function. Do you know what this is and how to use it?

***** no

OK, then here's a brief rundown and a few exercises:
Suppose you are signed on to a c.a.i. course (such as this one) and had to answer a question requiring you to multiply 6.85 and 3.84. You would type:

calc 6.85 x 3.48
I would type:

23.838

You would then answer the question you were asked to proceed with the course. Now, what is 973 times 842? (Use CALC to get the answer, and then type it in and send a "return".)

***** calc 973x842

819266.

***** 81922###
# PLEASE REPEAT
819266

Very good! Note that you don't have to use more than 4 sig fig if you don't want to.
Now, if you wanted to find 2.7805 plus 8.0384, you would type:

calc 2.7805 + 8.0384

What is 9.3785 + 3.2899? (Use calc to get the sum; then type in the sum to continue.)

***** 9.3785 + 3.2899

Don't forget the calc! Try again.

***** calc 9.3785 + 3.2899

12.6684

***** 12.6684

Well done.
! Now, subtracting.
Example:
calc 1.387 - 0.642
0.763
Now, what is 92.76 minus 203.09?

***** calc 92.76-203.09

-110.33

***** -110.33

Beautiful, , beautiful! Now, an example of division:
calc 736/9.26
79.4816414
Now, what is 89.62 divided by 22.63?

***** calc 89.62/22.63

3.9602297

***** 3.9602

Remarkable! What a computer is lost in you, ! Ah, well, anyhow . . .

Now let's try a few other uses of CALC, like-----

Exponentiation
Example: Find ten squared.
calc 10**2
Answer: 100.

Now, what is seven to the third power?

```
***** calc 7**3

      343.

***** 343
```

Beautiful, !
Another example: 4.67 to the (5.6)th power is?
calc 4.67**5.6
Answer: 5599.773
Okay, now what is 10.2 to the power of 1.5?
(Note: Remember not to use 'el's.)

```
***** calc 10.2**1.5

       32.57594

***** 32.575
```

Great!

Logarithms to base ten.

Example: what is the log (to the base ten) of 112?

calc log(112)
or
calc log10(112)
(Choose whichever is easier for you to remember. They both work.)
Now, what is the log to the base ten of 87.3?

```
***** 1.94
```

Beautiful! And what is the log to the base ten of 0.732?

```
***** calc log(.732)

       -0.1354889

***** -0.135
```

Logarithms to base e (natural logs)

Example: what is the natural log of -2.74?
calc ln(-2.74)
or
calc loge(-2.74)
Answer: 1.007956
Note that the absolute of the number is taken and the negative sign makes no difference.
Now, what is the natural log of 427?

```
***** ln 427
```

Just use calc to find the log, then type it in correctly to continue.

```
***** calc ln(427)

        6.056783

***** 6.057
```

Wonderful! And now,

Roots

Example: what is the square root of 0.7254?
calc sqrt(0.7254)
or
calc 0.7254**.5
or
calc 0.7254**(1/2)
What is the square root of 3.04?

UNITS AND UNIT CONVERSION FACTORS

UNIT CONVERSIONS

It is frequently necessary to express a quantity measured in one kind of unit, in terms of a different kind of unit. For example, we might wish to convert "22 inches" into units of FEET. This can be done by multiplying the original quantity by an appropriate UNIT CONVERSION factor:

(22 in) x (FACTOR) = 1.8 ft.

Do you know how to write this factor?

***** no

Forgetting about the numbers, for th. .., we want to convert INCHES into units of FEET. Shown underlined below are two possible conversion factors:

1) in x (ft/in) =

2) in x (in/ft) =

Now which factor (the one in (1) or the one in (2)) converts INCHES into units of FEET? (Answer 1 or 2)

***** 1

Correct! Equation (1) multiplies out as follows:

in x (ft/in) = ~~in~~ x (ft/~~in~~) = ft

Notice how the units that are unwanted in the final answer ("in") cancel out. So our conversion factor has the units of "ft/in". Now how many feet are there in an inch, anyway?

***** 1/12

Correct. The number of ft in one in. is 1/12, so our factor for converting in. into ft is:

(1/12)(ft/in) = (1ft/12in).

To prove it, we have:

(1 in) x (1 ft/12 in) = (1 ~~in~~) x (1 ft/12 ~~in~~) = (1/12) ft

How many ft are in 7 inches?

***** 7/12

Right! We have

(7 ~~in~~) x (1 ft/12 ~~in~~) = (7/12) in.

Suppose now that we want to convert FEET into INCHES:

(2 ft) x (FACTOR) = 24 in

What must our conversion factor look like now?

***** 12 in/1 ft

Exactly! There are

12 in. in 1 ft, or 12 in/1 ft,

so our conversion factor is

(12 in/1 ft).

How many inches in 20 ft.?

***** 240

Right; We have

(20 ~~ft~~) x (12 in/~~ft~~) = 240 in.

Now let's try another conversion factor. ENERGY can be measured in ergs or in calories; here's the relation between the two units:

1 erg = 2.39E-8 cal

Please type in the conversion factor that must be used to find the number of calories in a given number of ergs.

Now let's try converting from GRAMS into MILLILITERS (volume).
For this same substance (acetone), set up the conversion factor for the following:

____grams x (_____) = ______ml.

What goes inside the parentheses?

***** 1ml/.92g

Correct!   ___g x (1 ml/0.92 g) = ___ml.

Notice how the GRAMS terms cancel out.
Now let's look at a unit conversion involving POWERS of units - such as squares or cubes. A good example is the conversion of a VOLUME, expressed in cubic centimeters (cm**3) to cubic inches (in**3). By the way, a cm**3 is the same as a milliliter (ml). Say that we have a volume of 8 cm**3, and we wish to express this in cubic inches:

8 cm**3 x (________) = _____in**3

First, what must the UNITS in the conversion factor be (don't worry about the NUMBER yet)?

***** in**3/cm**3

Good.   cm**3 x (in**3/cm**3) = in**3;

notice how the unwanted units (cm**3) cancel out.

Now to make this a proper conversion factor, we must establish the numerical relation between in**3 and cm**3. To do this, you must know that:

1 in = 2.54 cm

How many cm**3 are there in 1 in**3?

***** calc 2.54**3

16.38702

***** 16.4

Very good;
1 in**3 = 16.4 cm**3

Now use this information to construct the complete factor for the conversion

___cm**3 x (______) = ____in**3

***** 1 in/16.4cm**3

Correct general format, but you are not expressing your cubas correctly; please try again.

***** 1 in**3/16.4cm**3

Excellent! Now find the number of in**3 in 80 cm**3 of water.
(please enter the correct answer)

***** calc 80/16.4

4.8780487

***** 4.88

Very good! Now let's convert 100 in**3 into units of cm**3:

100 in**3 x (______) = _______cm**3

Please type in the conversion factor here.

***** 16.4cm**3 / 1 in**3

Very good!
100 in**3 x (16.4 cm**3 / 1 in**3) = _______cm**3

Now how many cm**3 = 100 in**3 ?

***** 1640

***** 2.39E-8cal/1 erg

Excellent! We have:

1 ERGS x (2.39 E-8 cal/1 erg) = 2.39 E-8 CAL

One MOLE of a certain substance weighs 162 grams. Set up a conversion factor for expressing the number of MOLES contained in a given number of GRAMS of that substance.

***** (1 mole/162 g)

Correct!
We have:

x-GRAMS x (1 mole/162 gram) = y-MOLES.

i.e.,

1 gram = (1 mole/162 gram) = (1/162) mole

Some conversion factors have special names. An example is the one that converts a quantity of matter, expressed in volume units e.g. LITERS, into the corresponding quantity expressed in GRAMS. Do you know what this factor is called?

***** no

It's called DENSITY.
It is used like this:

LITERS x (density) = GRAMS

What two UNITS must be included in the conversion factor called "density"?
(You may abbreviate)

***** g/l

Right. Density is expressed in units of LITERS and GRAMS - the same two units that we are converting. How must they be arranged here?
(express the units as a fraction)

***** g/l

Good. We have:

LITERS x (grams/liter) = GRAMS

1.2 grams of alcohol occupies 1 milliliter (ml) of volume. What is the density of alcohol?

***** 1.2g/ml

Exactly! We have 1.2 grams/ml. Suppose that we have 30 ml of alcohol, and want to find its mass in grams. Set up the unit conversion factor that would convert VOLUME (ml) into MASS (grams).

***** 1 ml/1.2g

Very good! This gives us:

___ml x (1.2 g/ml) = ___grams

So what's the mass of 30 ml of alcohol?

***** calc 1.2x30

36.

***** 36 g

Great! Now suppose that 10 ml of acetone weighs 9.2 g. What would the conversion factor look like here?

___ml x (_______) = _____grams

What goes in the parentheses?

***** 9.2g/10 ml

Well, that's formally correct, but try dividing through by 10 to get a simpler factor.

***** .92g/1ml

Very good! We have:

____ml x (0.92g/1 ml) = ____grams

Again, the conversion factor is just the DENSITY - mass per unit volume.

Very good. It is frequently necessary to convert between units that are defined indirectly. For example, suppose that:

2 mabes = 1 pod (2 m = 1 p)

3 pods = 1 smud (3 p = 1 s)

Design a conversion factor that changes mabes into smuds:

______mabes x (______) = _______smuds

Can you do this?

***** no

Well, let's take it more slowly. You actually require TWO factors here:

___mabes x (factor 1) x (factor 2) = ____smuds

Factor 1 converts mabes to pods; factor 2 converts pods to smuds.
First, what does factor 1 look like? (remember, 2 m = 1 p)

***** 1p/2m

Good.

___mabes x (1 pod / 2 mabes) = _____pods

This is factor 1. Factor 2 effects the conversion:

___p x (__/__) = ___s

Remember, 3p = 1s. What goes inside the parentheses?

***** 1s/3p

Very good!

___pods x (1 smud / 3 pods) = ____smuds

The two factors together look like this:

mabes x (1p / 2m) x (1s / 3p) = ___smuds

Now combine them into one single conversion factor.

***** 1s/6m

Excellent! Now , just to see if you're getting it, set up a factor for the following:

___lums x (____) = ____tweet,

in which

6 lums = 1 scowl
1 scowl = 4 tweets

Please work it out on scratch paper, and then enter the completed factor (you may abbreviate the units).

***** 2t/3l

Terrific! >>>>END OF MOD 4

WEIGHT-WEIGHT RELATIONS, CONSERVATION OF MASS

WEIGHING IN

Simple weight measurements, made before and after a chemical reaction, illustrate some of the most fundamental laws of chemistry.

Example: Perhaps you know that magnesium metal burns in the presence of oxygen to form magnesium oxide.

How many grams of magnesium would you like to burn? Pick a number between 2 and 60, with no more than 3 sig fig.

***** 17.3 g

Ok, this will combine with oxygen to give you 28.7 g of magnesium oxide (You will learn how to calculate this later on in the course):

magnesium + oxygen	->	magnesium oxide
17.3 g		28.7 g

Now how many grams of oxygen will be used in this reaction?

***** 11.4g

Correct! By the way, can you name the principle or law that applies here?

***** conservation

Conservation of what?

***** mass

Right - the applicable law here is conservation of mass.
This is regarded as a "law" simply because human observation has yet to detect a deviation from this principle in any carefully executed chemical experiment.

Now let's get back to the first reaction we discussed - the combustion of magnesium to form magnesium oxide. Our reaction is:

magnesium	+ oxygen	->	magnesium oxide
17.3 g	11.4 g		28.7 g

Suppose now that we used only 8.65 g (half as much) of magnesium metal. How much magnesium oxide would be formed in this case?

***** 14.35g

No - remember that we have only half as much Mg to start with now, and try again (your answer should be to 3 sig fig).

***** 14.4g

Right! Since we started with only half the amount of Mg, we will use up only half as much oxygen, and get half as much product:

	magnesium	+ oxygen	->	magnesium oxide
first time:	17.3 g	11.4 g		28.7 g
this time:	8.65 g	5.7 g		14.3 g

Now let's use an arbitrary amount of Mg metal - 11.6 g, say. How much MgO is formed this time?

***** calc 28.7 x (11.6/17.3)

19.2439297

***** 19.2g

Right - so we have:

	magnesium	+ oxygen	->	magnesium oxide
first time:	17.3 g	11.4 g		28.7 g
this time:	11.6 g	7.6 g		19.2 g

At this point two things should be clear to you:

1. Mass is conserved in chemical changes
2. The masses of the various substances involved in chemical reaction are proportional to each other

This last one is a little vague . . . let's have one more look at it. Suppose that we have 17.3 g of Mg and 11.4 g of oxygen in a closed container. We saw a while ago that 28.7 g of MgO would be formed. Now, what would happen if 24.2 g of oxygen were present, with the same amount of Mg as before? How much MgO will be formed this time?

***** 28.7g

Good! In this case, the oxygen is said to be present IN EXCESS: there is more than is needed, so the amount present will have no effect on the quantity of product formed.

One other important thing to notice--there is only one compound called magnesium oxide; the presence of excess oxygen does not result in the combination of the same amount of magnesium with MORE oxygen--the ratio between the weights of oxygen and magnesium in magnesium oxide is CONSTANT, and this constant is a property of magnesium oxide. What is the name of the law of chemical combination that is illustrated here?

***** constant composition

We are referring to the LAW OF DEFINITE PROPORTIONS.
What is the ratio of the weight of magnesium to the weight of oxygen in magnesium oxide?

***** calc 17.3/11.4

1.5175438

***** 1.51

Great! OK, and now let's find the percent composition by weight of magnesium oxide. First find the percent by weight of magnesium in this compound.

***** help

We have:

magnesium + oxygen -> magnesium oxide
x grams y grams

What weight of magnesium oxide is produced?

***** x+y grams

OK--Now what fraction of this total weight consists of magnesium?
(answer in terms of x and y).

***** x/(x+y)

Right--the fraction of Mg present is x/(x+y).
OK, the percent is just the fraction times 100. So the percent magnesium is 100x/(x+y).
Now, in your first reaction, you had 17.3 grams of Mg, and this produced 28.7 grams of magnesium oxide.
What is the fraction of Mg here?

***** 17.3/28.7

OK--and the percent by weight of Mg will be?

***** calc 17.3/28.7

0.6027874

***** 60.3

Correct. Now let's see if you can make use of the weight ratio data presented in a slightly different manner. The weight ratio of strontium to oxygen in the compound strontium oxide is 5.47 to 1. What is the weight-% of strontium in this compound?

***** calc 5.47/6.47

0.8454404

***** 84.5

Very good--you obviously understand this now.
You should now have a better grasp of the following concepts:

conservation of mass
Law of Definite Proportions (weight ratios and their constancy)
Proportionality of weights in chemical reactions and the Law of Constant Composition
Percent composition (by weight) from weight ratio data

Notice that all these observations were made by means of weight measurements on large (weighable) samples, and that we have not used atomic theory at all. Nevertheless, these observations all lend support to the atomic theory of matter.

>>>/END OF MOD 6

LAW OF MULTIPLE PROPORTIONS

DOUBLE TROUBLE

There are many cases known in which two elements will combine under different conditions to yield two (or more) distinct compounds. For example, 25.4 g of copper will combine with 6.4 g of oxygen to form an oxide:

copper + oxygen -> copper oxide 1

25.4 g   6.4 g   31.8 g

Under different experimental conditions, it is possible to prepare a different oxide in which 19.1 g of copper is combined with 2.4 g of oxygen:

copper + oxygen -> copper oxide 2

19.1 g   2.4 g   21.5 g

QUESTION: Which oxide (1 or 2) contains more copper per fixed amount of oxygen?

***** 2

Right! We would now like to compare the two oxides, to see how much oxygen reacts with a fixed weight of copper in each case. We saw that 6.4 g of oxygen reacts with 25.4 g of copper to form oxide 1. Now, can you find how many grams of oxygen would react with the same weight of copper (25.4 g) to form oxide 2?

***** no

We want to find how many grams of oxygen would combine with 25.4 g of copper to form oxide 2:

copper + oxygen

19.1 g   2.4 g -> oxide 2

25.4 g   ??? g -> oxide 2

Oxide 2 is defined by the fixed proportion with which copper and oxygen combine to form this compound. What is this proportion (express it as a ratio or a quotient)?

***** 19.1/2.4

Good! We have (19.1 g)/(2.4 g) = 7.95 (let's call it 8.0).
Now this ratio can be satisfied by any combination of weights of copper and oxygen that yield the same quotient; i.e., you need not use 19.1 g of Cu and 5.1 g of oxygen to make oxide 2. Suppose you had only 10 g of Cu available. Would you require more or less oxygen in this case?

***** less

Of course!
In order to maintain the same weight ratio, we will use less oxygen here. With 10 g of copper, we have only 10/19.1 as much as we had before. By what factor will the weight of oxygen needed be reduced?

***** same factor

Excellent!
We have only 10/19.1 = 0.52 as much copper, so we require only 0.52 as much oxygen.
You get the idea, I hope.

Now let's get back to the main exercise. Instead of 10 grams, we have 25.4 g of copper available. By what factor is this weight greater than 19.1 g?

***** 25.4/19.1

. . . = 1.33!
OK, we have 1.33 times as much copper here, so we need 1.33 times as much oxygen.
What weight of oxygen will we need?
(look at the first of the pair of equations written some lines above
to refresh your memory)

***** calc 2.4x1.33

3.192

** 3.19g

OK, we have:

copper + oxygen

<u>25.4</u> g   <u>6.4</u> g -> oxide 1

<u>25.4</u> g   <u>3.19</u> g -> oxide 2

Great! You have just discovered the Law of Multiple Proportions! (Ratio of "small, whole numbers", etc.) If there is twice as much oxygen per fixed weight of copper in oxide 1 as there is in oxide 2, and IF the formula of oxide 2 is CuO (1 copper atom to 1 oxygen atom), then what is the formula of oxide 1?

***** Cu_2O

But this formula has only HALF as much oxygen as CuO. Please try again.

***** CuO_2

Very good!
We have:

copper + oxygen

oxide 1: <u>25.4</u> g   <u>6.4</u> g -> CuO_2

oxide 2: <u>25.4</u> g   <u>3.2</u> g -> CuO

Notice how the subscript in the formula is proportional to the weight of oxygen. (You recall that "1" subscripts are not written--they are understood.) Remember that we ASSUMED that oxide 2 was CuO. Now it turns out that the formula of OXIDE 1 (not oxide 2) is actually CuO! What does this make oxide 2?

***** Cu_2O

Right!
From all of this, you should see how weight ratios can give a clue to the formulas compounds made of the same elements, but in different proportions. However, these ratios alone cannot tell us the true formulas. Thus the weight data we have found is consistent with any of the following formulas:

copper	oxygen	possible formulas		
25.4 g	6.4 g	CuO	CuO_2	CuO_3
or			or	
25.4 g	3.2 g	Cu_2O	CuO	Cu_2O_3

The true set of formulas must be found by independent means.
>>>>END OF MOD 7;

RELATIVE WEIGHTS OF ATOMS; ATOMIC WEIGHTS

WEIGHING A LOT

In the previous section, we used simple weight measurements to deduce some of the fundamental laws of chemistry, without reference to individual atoms. Let us now assume that matter is composed of atoms. Since we cannot see them, atoms must be very small, and any weights that we can measure in practical experiments must represent very large numbers of atoms. Atoms of different elements will have different weights. How can we find the relative weights of different kinds of atoms when we cannot weigh them individually?

ANSWER: We can weigh large (weighable), and EQUAL amounts of two kinds of atoms.

EXAMPLE: Magnesium metal burns in oxygen to form magnesium oxide (remember???); let us ASSUME that this compound contains one magnesium atom for each oxygen atom:

Mg + O -> MgO

In an experiment, 4.86 g of Mg yields 8.06 g of magnesium oxide. First, how many grams of oxygen entered into this reaction?

***** 3.2g

OK, we have:

Mg	+	O	->	MgO
4.86 g		3.20 g		8.06 g

Now does the atom of Mg weigh MORE or LESS than the atom of oxygen?

***** more

Right! From the weights of Mg and O that enter into this reaction, we see that the Mg atom weighs 4.86/3.20 times as much as the atom of oxygen (assuming that magnesium oxide is MgO). Now, as you may know, it became customary long ago to compare the relative weights of atoms on a scale on which oxygen was assigned a weight of exactly 16.000. Now if we call the weight of the oxygen atom 16.0, what would be the relative weight of the magnesium atom?

***** dont know

In essence, we are asking how much Mg would react with 16 g of oxygen:

Mg	+	O	->	MgO
4.86 g		3.20 g		8.06 g
?? g		16.0 g		

Now we have 16.0/3.20 = 5.00 times as much oxygen on the second line. By what factor will this alter the weight of magnesium required?

***** 5

Good.
Now how much Mg is required?

***** calc 5 x 4.86

24.3

***** 24.3g

Very good! So everything on the second line below the equation is just 16.0/3.20 times that on the first line:

Mg	+	O	->	MgO
4.86 g		3.20 g		8.06 g
24.3 g		16.0 g		40.3 g

We see that 24.3 grams of Mg reacts with 16 grams of oxygen; this means that the relative weight of Mg is what?

***** 24.3/16

No--remember the definition of relative weight based on oxygen = 16.0 .

***** 24.3

Right! And these relative weights are called ATOMIC WEIGHTS--a confusing misnomer, to be sure: ATOMIC WEIGHT and WEIGHT OF AN ATOM are two different things. More on this later. Now the only trouble with this is that we had to ASSUME that the formula of magnesium oxide is MgO--a 1:1 ratio of Mg to O. It turns out that this assumption, for many simple oxygen compounds, is quite correct. However, this is not always true. Let's look at water, the oxide of hydrogen. Since hydrogen is the lightest atom, it should have a relative weight of 1. So let's look at an experiment with oxygen and hydrogen:

hydrogen + oxygen -> water

ALCHEM
mod09

THE MOLE CONCEPT

WHAT ARE MOLES GOOD FOR, ANYWAY?
". . . take 4 oxygen atoms, add 1 chlorine, and stir well, mixing in 1 hydrogen atom . . ."
Because individual atoms are too small to weigh out, it is more convenient to consider the weights of fixed large numbers of atoms when specifying the recipes for goodies such as perchloric acid. But even if we took 40 oxygens, or 400000000 oxygens, we would still not have enough to weigh. Instead, we need more like 10**20 or 10e25. By the way, do you know what both of these numbers mean?

***** yes

Fine - you understand exponential notation; we will use the "e" from here on.
OK, instead of picking some nice round number as our "standard quantity of atoms", it is more convenient to pick that number of atoms whose weight is the relative or atomic weight of the element. For example, our standard working quantity of hydrogen atoms will be as many H atoms as it takes to make up a total weight of 1.008 grams, which is the atomic weight of H. This number of atoms is called ONE MOLE.

What is the weight of half a mole of H atoms?

***** .5004g

Division error- there are too many 0's in your answer. Try again.

***** .504g

Very good!
Now what does 1 mole of strontium (Sr) weigh? (Atomic weight of Sr = 87.6 g/mole)

***** 87.6

This is the ATOMIC WEIGHT of Sr, but your answer must be expressed in grams.

***** 87.6g

Correct!

How many grams of cobalt (at wt = 58.9) are there in
1.21 mole of Co?

***** calc 1.21 x 58.9

71.269

***** 71.3g

Very good!
OK, here are a few more!
Now find the weight of gold in 3.06 moles of gold (at wt of Au = 197):

***** calc 3.06 x 197

602.82

***** 603g

Right! How many grams of nitrogen would there be in 5.76e5 moles of NITROGEN (at wt = 14.01)?

***** calc 5.76 x 14.01

80.6976

***** 8.07E6

Well done! Now - let's suppose that you have 2 piles:

1 mole of oxygen atoms (at. wt. 16)	and	1 mole of carbon atoms (at. wt. 12)

Does the oxygen pile contain more, less, or the same number of atoms as the carbon pile? (Answer m, l, or s.)

***** s

Right! You evidently understand that a mole is a NUMBER;
Do you know the VALUE of this number, or even what it is called?

***** Avogadros no.

Good! It's called Avogadro's number, and its value is 6.02e23 (or 6.02 x 10**23).
So if we have 6.02e23 oxygen atoms, how many moles of oxygen do we have?

***** 1

OK, ...and if we have 18.06e23 zinc atoms, how many moles of zinc do we have?

***** 3

Good.
Now what if we have 2.0e19 (2.0 x 10**19) atoms of gold - how many moles here?

***** calc 2.0/6.02

0.3322259

***** .332E-4

Correct!
Now, finally, suppose that you have just succeeded in creating a new element in an atomic reactor--

We'll call our new element lowerium (in honor of its eminent discoverer!). Now, you have made only one atom of this precious substance. How many moles of this element do you have?

***** calc 1/6.02

0.1661129

***** .166E-23

Great- you're right with it!
By this time, you should have picked up two new ideas:

1) A MOLE is a number: 6.02e23 .
2) This number of atoms of any given element has a mass, in grams, identical to the atomic (or relative) weight of that element.

The importance of Avogadro's number, then, is that it CONNECTS

ATOMIC WEIGHT--------with--------WEIGHT OF AN ATOM

Th• use of the mole concept is that it is easier to compare the weights of some fixed large number of atoms, than of SINGLE atoms. A mole is just this large fixed number. Think about this for a while, and then send a return when you wish to proceed.

*****

OK - the atomic weight ofsulfur is 32.06 g/mole. Do you think you can find the weight of 1 atom of sulfur? (y or n, please.)

***** y

OK,workit out now!

***** 32###
# PLEASE REPEAT
calc 32.06/6.02

5.3255813

***** 5.32E-23g

Great!
And now, what would 4 atoms of oxygen (atomic weight 16g/mole) weigh?

***** calc (4 x 16)/6.02

10.6312292

***** 10.6E-23g

Correct!

Now this time we have 1.00 E+17 atoms of chlorine; how much would thisweigh? (Atomic weight Cl = 35.45 g/mole.)

***** calc 35.45/6.02

5.8887043

***** 5.89E-6g

Very good!
OK, you should now have a pretty clear idea ofthe relation between atomic weights, weights of atoms, weights of substances (e.g.,"13 g of iron", etc.), and the definition of the mole.

>>>>END OF MOD 9; time= 14 minutes.

BALANCING SIMPLE EQUATIONS

IN THE BALANCE
Let's start with something simple - like the hydrogen atom. Do you know the symbol for this element?

***** H

Right. The symbol for hydrogen is H. How would you express "two hydrogen atoms" in chemical symbolism?

***** 2H

Exactly!
"2H" means "two hydrogen atoms". But do you know what "H_2" means?

***** 1 hydrogen molecule

Correct! A hydrogen MOLECULE!
This is just two hydrogen atoms, joined together: H-H, or H2. If I weren't a computer, I would have typed that "2" as a subscript following the "H". For convenience, we'll just pretend that numbers immediately following symbols for elements are subscripts, each indicating the quantity of that kind of atom in the molecule. Thus the hydrogen molecule would be "H2".

How would you express "two hydrogen molecules" on the typewriter?

***** 2H2

Perfect!
You may already know that many elements exist as diatomic molecules (diatomic = TWO atoms) in their pure state. Fluorine (F) is another element that behaves this way. Write the formula for a fluorine atom.

***** F

O.K.
And how about a fluorine molecule?

***** F2

Right!
Notice, by the way, that if we just say "hydrogen" or "fluorine", it is not clear whether we refer to atoms or to the diatomic molecules. Oxygen also forms a diatomic molecule, O2. But this element can also exist as a TRiatomic molecule, called "ozone". Type in the formula for ozone.

***** O3

Very good!
Now how about "two molecules of ozone". How would you represent this?

***** 2O3

Right.
And how many ATOMS of oxygen are contained, or bound up in, two ozone molecules?

***** 6

Very good.

Ozone is an unstable substance that tends to decompose into oxygen. Suppose that we had two molecules of ozone. How many oxygen molecules could we get?

***** 3

Right!
We can represent this process by means of a chemical equation:

ozone --> oxygen

O3 --> O2

Since a chemical equation is a statement of FACT, it must be consistent with "reality", which tells us that in chemical processes, elements (atoms) are neither created nor destroyed. A chemical equation that is consistent with this particular fact is said to be balanced:

2 O3 --> 3 O2

(6 atoms) (6 atoms)

Please hit the "return" when you are ready to proceed.

*****

Suppose that you have 80 molecules of ozone. Would the equation, as written above, still apply? (answer yes or no , please)

***** yes

Right! You evidently understand that the coefficients in a chemical equation really stand for RATIOS. The equation written above says that the ratio of the number of molecules of oxygen formed, to the number of ozone molecules consumed, is 3:2, or 3/2 (or 1.5).

Now suppose that we had 6198 molecules of ozone, how many molecules of oxygen could our reaction give us?

***** calc (3/2)x6198

9297.

***** 9297

Very good!
Here's another.

Phosphorus and bromine react to form phosphorus tribromide:

___Br2 + P --> PBr3

Commence the process of balancing this equation by typing in the number of Br2 molecules (less than 20, please!) you would like to try using.

***** 6

Since each Br2 molecule contains two Br atoms, this gives you 12 atoms of Br to work with on the left.
Now how many PBr3 molecules can you get from this number of Br atoms?

***** 4

Good! We have:

6 Br2 + P --> 4 PBr3
And how many P atoms do we need?

***** 4

Very good! That's it.

The combustion of hydrogen with oxygen to form water vapor is a well-known reaction.
Just to be different, I will pick a random number and insert it as a coefficient ahead of the oxygen:

__H2 + 9 O2 --> __H2O
Now with 9 oxygen molecules as shown, how many hydrogen molecules are required?

***** 18

Right - twice as many H2's are needed.
And how many H2O molecules are produced?

***** 9

NO - notice that each O2 molecule contains enough oxygen for TWO H2O molecules.
Now try again.

***** 18

Certainly!

Our equation is:

18 H2 + 9 O2 --> 18 H2O

What number must we now divide thru by in order to produce an acceptable equation?

***** 9

Right; the equation is now balanced and written properly:

2 H2 + O2 --> 2 H2O

Do you want to try this again?

***** no

OK, Now finally here's an equation representing the combustion of a hydrocarbon fuel; we'll let you start by typing a number under any one component; this will be the coefficient of that component in the reaction. Use the space bar to position the typeball under the desired term.

C4H10 + O2 --> CO2 + H2O

*****   8

OK, you are starting with 8 molecules of oxygen;
How many O-atoms does this amount to?

***** 16

Now how many O atoms are required to completely oxidize all the C and H in one molecule of C4H10?

***** 13

Correct; Now you had 16 oxygen atoms - 3MORE than the minimum number required to oxidize all the C and H in one molecule of C4H10. You should therefore cut down on the number of oxygen atoms so you will have none left over. You need only 13 oxygen atoms - how many O2 MOLECULES does this amount to?

***** 6.5

OK, so we have:

C4H10 + 6.5 O2 --> CO2 + H2O

But we don't like to use non-integral coefficients like "6.5".
What number of O2 molecules should you use instead?

***** 13

OK - and since this is twice as much O2 as is required to oxidize one molecule of C4H10,
what coefficient do we write in front of the butane?

***** 2

Of course!
We now have:

2 C4H10 + 13 O2 --> ___CO2 + ___H2O.

How many CO2's do we get?

***** 8

Correct.
And how about H2O - what coefficient goes here?

***** 10

Excellent.
That's it - the equation is balanced.
You have balanced the equation just once; we would now like you to try doing it again, but this time commencing by placing your first coefficient ahead of some OTHER molecule than the one you first started with last time. Once again, use the space bar to position the typeball under the term you wish to deal with first.

C4H10 + O2 --> CO2 + H2O

*****   10

OK, you are starting with the carbon dioxide; there are 10 carbon atoms in 10 molecules of CO2.
How many molecules of C4H10 are required to supply this number of carbons?

***** 3

NO; notice that each butane molecule contains FOUR carbons, so can yield 4 CO2 molecules. How many butanes are needed to supply 10 CO2 molecules?

***** 2.5

Right;
So clearly, the number of CO2 molecules you can obtain from this reaction must always be some MULTIPLE of 4.
Please enter a new value for the number of molecules of CO2 you wish to use in balancing the equation.

***** 12

OK, there are 12 carbon atoms in 12 molecules of CO2.
How many molecules of C4H10 are required to supply this number of carbons?

***** 3

Right;
You need only 1/4 as many C4H10 molecules as CO2 molecules in the equation; you were wise to choose a multiple of 4 CO2 molecules!
Now how many water molecules can you get from the hydrogens contained in 3 molecules of C4H10?

***** 15

Correct! We now have:

3 C4H10 + ___O2 --> 12 CO2 + 15 H2O

Now how many oxygen ATOMS do we require for all this?

***** 39

3 C4H10 + 39 O2 --> 12 CO2 + 15 H2O

And that's it!

FORMULA & MOLECULAR WEIGHTS

```
FORMULA WEIGHTS

One mole of carbon atoms weighs 12.01 grams.  What is the ATOMIC WEIGHT of carbon?

***** 12

Please answer to 3 sig. figures precision.

***** 12.01

+  What is the mass of one ATOM of C?

***** calc 12.01/6.02

        1.9950166

***** 2.00e-23g

+   The atomic wt. of oxygen is 16.0;  how much does 12.04 E23 atoms of O weigh?

***** calc 16.0/6.02

What's (2 moles) x (16.0 g/mole) ?

***** 32g

Please include 3 sig. figures in your answer.

***** 32.0g

Now carbon burns in air to give carbon dioxide, CO2.  How many atoms are there in one
molecule of CO2?

***** 3

+  And how many atoms are there in ONE MOLE of CO2?

***** 18.06e23

Correct  18.06e23  or  1.81e24.
Now we found that:

     1 mole of C = 12.0 g;        1 mole of O = 16.0 g.

What would 1 mole of CO2 weigh?

***** 44.0g

+  What would one MOLECULE of CO2 weigh?

***** calc 44/6.02

        7.30897

***** 7.31e-23g

Correct;
Notice that the molecular weight is just the sum of the atomic weights of all the atoms
in one molecule.
What is the molecular weight of sulfuric acid, H2SO4?
(H = 1.01, S = 32.1, O = 16.0)

***** 98.1

+  I have 10.3 g of H2SO4;  how many moles does this correspond to?

***** calc 10.3/98.1

        0.1049949

***** .005

+  Here is 3.4 moles of H2SO4 - what does this amount of acid weigh?

***** calc 3.4x98.1

      333.54

***** 334g

.+  Ordinary sugar has the formula C12 H22 O12.  What would be the weight, in grams,
of 1 mole of sugar?
      (C = 12, H = 1.0, O = 16)

***** calc 144 + 22 +(12x16)

      358.

***** 358
```

NAMES & SYMBOLS OF ELEMENTS

It's important for you to know the names and symbols of the principal elements. There are two ways we can give you exercise on this -

1) I type the name of an element and you type the symbol for it.

2) I type the symbol and you type the name of the element.
(In either case, I'll help you if you get stuck!)

Can you type well enough to do (2) ?
(Names of elements are of course longer than symbols;) Answer yes or no , please.

***** yes

Good; In that case, we will try both. I will select the elements at random from a list. If I type a name, you type the symbol; If I type a symbol, you type the name. If your answer is correct, I will scratch the element off my list. If you make a mistake, I will save the element and pick it again later.
If you are stuck, type a ? and I will give you the answer - but will ask you again later! Please send a carriage return when you are ready to start.

*****

ANTIMONY

***** An

NO.

***** At

Sb (Lat. Stibium); please enter.

***** Sb

Sb; a metal.

Na

***** sodium

Mn

***** maganese

It's spelled MANGANESE ; please enter.

***** manganese

LEAD

***** Le

NO.
Pb: please enter.

***** Pb

Pb;
XENON

***** Xe

Xe; an "inert"gas
Rarest of the stable elements: 0.000009% in air; >Gr. xenos="strange one"

LEAD

***** Pb

Pb;
>Lat. Plumbum (whence "plumber"); known in antiquity.

ARSENIC

***** Ar

NO.

***** As

As;

Si

***** silicone

It's spelled SILICON ; please enter.

***** silicon

WHAT'S THE FORMULA?

How can we determine the FORMULA of a chemical compound, when we cannot see, and thus count, the numbers of each kind of atom present in the molecule? There are two ways: one is to WEIGH the amounts of the elements that react to form the compound, and then convert these weights to moles. For example:

0.875 g of Al reacted with chlorine (Cl2) to give 4.325 g of compound. What is its formula? i.e., what are x and y in the formula Al(x)Cl(y)?

FIRST, find the weights that reacted. How much chlorine is in this compound?

***** calc 4.325 - .875

3.45

***** 3.45 g

Good- we see that 4.325 g of our compound contains .875 g of Al and 3.450 g of Cl. We must now convert these relative MASSES into relative numbers of MOLES. Each mole of Al weighs 27.0 g. How many moles of Al are there in .875 g of Al?

***** calc .875/27

0.0324074

***** .0324 mole

Good - and now for the chlorine. There are 3.475 g in this compound; how many moles is this? (at wt of Cl = 35.5)

***** calc 3.475/35.5

0.0978873

***** .0979 mole

Correct. In terms of MOLES now, we have:

Al	Cl
.0324 mole	.0979 mole

Now this is not a proper formula - but it does represent the mole PROPORTIONS - which will be the same in the formula. What is the MOLE RATIO of Cl to Al in this compound?

***** calc .0979/.0324

3.0216049

***** 3:1

Right - call it 3:1 or 3.
So for every THREE chlorine atoms, there are how many ALUMINUM atoms?

***** 1

Certainly - So how would you write the formula?

***** AlCl3

Great! Remember that this is only the SIMPLEST formula, consistent with the mole ratio of Al:Cl that we determined. (The ACTUAL formula is Al2Cl6, but that's another story!)

Now the other way to determine formulas is just the reverse: Instead of MAKING a compound, we BREAK IT DOWN, and weigh the amounts of elements we get. This is called ANALYSIS, and the results are usually given in terms of WEIGHT PERCENTS of the various elements present.
For example:

A certain compound is found, upon analysis, to have the following weight-percent composition:

42.9% C 57.1% O

How many grams of carbon are there in 100 grams of the compound?

***** 42.9 g

How many MOLES of carbon (at wt = 12.0) are in 100 grams of this compound?

***** 42.9/12

Please divide it out, using CALC, and enter the answer.

***** calc 42.9/12

***** 3.58 moles

Right! OK, now let's look at the oxygen. How many grams of oxygen in 100 g of the compound?

***** 57.1g

Good. Each mole of oxygen atoms weighs 16.0 grams. How many moles of oxygen are there in 100 g of the compound?

***** calc 57.1/16

3.56875

***** 3.57

We now have the beginnings of a formula, because we know the relative number of moles of each element present: 3.575 or 3.58 moles of C, and 3.57 moles of O. Rounding down to 2 sig figures (owing to exp. error in the percent data), we have:

C(3.6) O(3.6)

There are 3.6 moles of each element present in 100 g of compound. This means that there are EQUAL NUMBERS OF MOLES, and therefore EQUAL NUMBERS of both atoms present. What would be the simplest formula of such a compound?

***** CO

Notice that the number "3.6" arose only because we considered an ARBITRARY amount- 100 grams, of the compound. We could just as well have figured the nos. of moles of the elements in 1 gram, in 37 grams, or 9004 grams. In any case the MOLE RATIO of C:O would have been 1:1, no matter what the actual number of moles (3.6 or 36001); all we can find here is the SIMPLEST possible formula.

Now let's try another - which will turn out to have a slightly more complicated formula:

a compound contains 90.6% Pb (at wt = 207)
and 9.4% O (at wt = 16.0)

First, we want to find the relative numbers of moles of Pb and O in an arbitrary weight of the compound.

How many moles of Pb are there in 100 g of the compound?

***** calc 90.6/207

0.4376811

***** .438 mole

And how many moles of O are there in 100 g of the compound?

***** calc 9.4/16

0.5875

***** .588 mole

OK - we have the following mole ratio:

Pb	O
.438 mole	.588 mole

Now this doesn't look very promising - no "small, whole numbers" here; but wait! There is a sure-fire way to get at least one such number: divide thru by one of the numbers we have just determined:

Pb	O
.438/.438	.588/.438

For the Pb, what relative no. of moles do we have now?

***** 1

Success! A small, whole number if ever there was one!
How about oxygen - what mole ratio here?

***** calc .588/.438

1.3424657

***** 1.34

So we have:

The region of space (centered about the nucleus) in which the electron manifests itself is called an ORBITAL. Modern atomic theory characterizes each orbital by a set of three QUANTUM NUMBERS. Do you know what the most fundamental of these quantum numbers is called?

***** n

Right - this is the PRINCIPAL quantum number.
What is the lowest value that n can take?

***** 1

And what is the next larger value of n?

***** 2

OK, so n takes integral values 1, 2, 3, etc. The larger the value of n, the larger the electron cloud. n corresponds to the "orbit" number of the old Bohr model; we still refer to the "1-shell", the "2-shell", etc.

Now for any value of n, we can define another quantum number l. l can have any integral value from 0 to n-1. What values can l have when n=2?

***** 0 and 1

Right. How many different values can l have when n=4?

***** 3

NO - the minimum value of l is 0; the maximum value is n-1 = 4-1. Now try.

***** 4

Good. In general, then, there are n values of l for each value of n.
Orbitals coresponding to different l-values are given alphabetic names:

s orbitals: l=0; p orbitals: l=1; d orbitals: l=2

f orbitals: l=3; g orbitals: l=4; ...etc...

We can thus designate an orbital by its PRINCIPAL QUANTUM NUMBER n, followed by the letter indicating the l-value.

What is the value of n for a 3p orbital?

***** 3

And what is the value of l here?

***** 1

Now enter the values of n AND l for the following orbitals:
(just enter the two numbers, one after the other)

2s ?

***** 2 0

+ 3s ?

***** 3 0

+ 3d ?

***** 3 2

+ 4p ?

***** 4 1

+ 5s ?

***** 5 0

+ 2p ?

***** 2 1

+ What do we call an orbital for which n=4 and l=3?

***** 4f

Good! And how about n=2, l=0?

***** 2s

n=4, l=1?

***** 4p

And finally, n=1, l=0?

***** 1s

Right - this is the lowest-energy orbital possible. Can we have 1p orbitals?

***** no

Certainly not; the quantum no. l can have a max. value of n-1 which in this case is 0, so only s-orbitals are allowed in the 1-shell. What is the lowest value of n for which d-orbitals are possible?

***** 3

Correct! So what different kinds of orbitals are available in the n=3 shell?

***** s p d

OK, and how about for the n=2 shell?

***** s p

And finally, what orbitals are possible for the n=5 shell?

***** s p d f g

Excellent!

Notice again that there are n values of l possible for any value of n.

Now we must introduce another quantum number, m. For any value of l, m can take the integral values -l...0...+l. There are then 2l+1 values of m for any value of l (the 1 comes in because m=0 is allowed).

When l=2, what values can m take? (list in numerical order)

***** -2 -1 0 +1 +2

Exactly! There are FIVE d-orbitals possible, having these values of m. And what values of m are possible for s-orbitals?

***** 0

Right. There is only ONE possible s-orbital. What m-values are possible for p-orbitals?

***** -1 0 +1

OK, we have THREE kinds of p-orbitals, having m=-1, 0, and +1. We see, then, that there can be

only 1 s-orbital (l=0)

but 3 p-orbitals (l=1)

and 5 d-orbitals (l=2) .....

Would you care to guess how many f-orbitals (l=3) there can be?

***** 7

Well done; the m-values are -3, -2, -1, 0, +1, +2, +3. In general, there are 2l+1 possible values of m, and hence this number of ORBITALS, for a given value of l.

Now EACH orbital can accommodate TWO electrons. Do you know what is DIFFERENT about the two electrons in each orbital?

***** they have different spins

Exactly - Their SPINS are opposite, corresponding to +1 and -1 values of the spin quantum number s. In any case, the rule is NO MORE THAN TWO electrons per orbital.

How many 3s electrons can there be in an atom?

***** 2

Correct. How many 2p electrons can there be?

***** 2

NO - remember that there are 3 values of m here. Try again.

***** 6

How about 6d electrons? How many can there be?

***** 10

Finally, how many 4f (or 5f, or 6f!) electrons can there be in any atom?

***** 14

ELECTRONS IN ATOMS

An ORBITAL is a region of space in which an electron has a high probability of manifesting itself. Different orbitals - 4s, 2p, 3d, for example, correspond to different POTENTIAL ENERGIES of the electrons that occupy them.

POTENTIAL ENERGY is the energy a body has by virtue of its ___?___
(What goes in the blank)

***** location

Right! Potential energy depends on the LOCATION of an object in a force field. If the object in question is an electron in an atom, what is the source of the force field?

***** the nucleus

Good!
The electrons of an atom are attracted to the positive nucleus. Suppose we have an electron in an orbital fairly close to the nucleus. Will its potential energy be higher or lower than that of one that is in a more distant orbital?
(answer h or l .)

***** l

Certainly! ...just like a book closer to the floor!

Now the potential energy of an atomic orbital depends mainly on the value of the PRINCIPAL QUANTUM NUMBER, n, for it is n that determines the AVERAGE DISTANCE of the electron (or electron cloud) from the nucleus.

The energy also depends, but in a very secondary way, on the value of the quantum number l. Generally, the trend runs

s (lowest) p d f (highest)

What is the LOWEST-energy orbital possible in an atom?

***** 1s

Now in order to show how many ELECTRONS a particular orbital contains, we follow the orbital designation with a number - ordinarily a superscript: thus "1s2" means that there are TWO electrons in a certain orbital. How would we designate the electron configuration of HYDROGEN, the simplest atom?

***** 1s1

Right! The next atom, helium, has an atomic number (nuclear charge) of 2, so it contains 2 electrons. What is the configuration of He?

***** 1s2

Right. The next element, lithium, has an atomic number of 3. Into which orbital do the "first" two electrons go?

***** 1s

Good. And into which orbital does the third electron go?

***** 2s

Correct. So what is the complete electron configuration of Li?

***** 1s2 2s1

Very good! We have, then, the first few elements:

at no:	1	2	3	4	5
element:	H	He	Li	Be	B
config:	1s1	1s2	1s2 2s1	1s2 2s2	_____

Into which orbital does the "fifth" electron in Boron (B) go?

***** 2p

Good. So the OUTER SHELL configuration of boron is what?

***** 2s2 2p1

Excellent! The next few elements are:

at no.	5	6	7	8	9	10
element:	B	C	N	O	F	Ne
config: 2s2 2p1						

How many 2p electrons does Carbon (C) have?

***** 2

OK. How many OUTER SHELL electrons does Nitrogen (N) have?

***** 3

How many electrons are in the 2s and 2p levels of N?

***** 5

Right. And Neon?

***** 8

What is the outer-shell (n=2) configuration of Neon?

***** 2s2 2p6

Very good. Neon has a total of ten electrons. How many of these are in the outer (n=2) shell?

***** 8

Correct. The next element after neon is Sodium (Na). What is the atomic number of sodium?

***** 11

Right. What is the outer-shell electron configuration of Na?

***** 3s1

Very good! We have:

at no.	10	11	12	13
symbol	Ne	Na	Mg	Al
config.	2s2 2p6	3s1	_____	_____

What goes in the blank under Magnesium (Mg)?

***** 3s2

Of course! And what goes in the blank under Aluminum (Al)?

***** 3s3

NO - we can NEVER have more than two 3s electrons.

***** 3s2 3p1

Great! Aluminum is 3p1, and in the next several elements, the 3p orbitals get filled. What would be the atomic number of the element in which the outer-shell configuration is 3s2 3p6?

***** 18

Right. This would be Argon, with 1s2 2s2 2p6 3s2 3p6. Notice the "s2 p6" CLOSED OUTER-SHELL configuration. Argon is therefore similar to Neon (1s2 2s2 2p6) and to Helium (1s2) in that they all have filled outer shells.

What are the ATOMIC NUMBERS of these three filled-outer-shell elements? (Enter all three, one after the other)

***** 2 10 18

Very good! Notice that the difference is EIGHT electrons in each case; each "closed-shell" element has two s-electrons and six p-electrons (s2 p6) more than the preceeding one.
Argon, element 18, has the 3s2 3p6 closed shell. The next element is potassium (K). What is it's outer-shell configuration?

***** 4s 1

Right! And Calcium, the next element?

***** 4s2

Good. And Scandium (Sc), the next element?

***** 4s23d1

Fine - you remembered that the 3d shell begins to fill here.
What, then, would be the electron configuration of Sc, showing ALL the n=3 and n=4 orbitals that are occupied?

***** 3s2 3p6 3d1 4s2

Very good!

(Ne) 3s2 3p6 3d1 4s2

This is one way of representing the configuration of Sc; the "(Ne)" indicates the 1s2 2s2 2p6 part of the configuration that corresponds to the element neon. We could also write this configuration using the symbol of the next inert gas, Argon;

(Ar) ____________

What goes in the blank space? (remember that Ar has 8 more electrons than Ne)

***** 3d1 4s2

Exactly! This is the preferred way of writing configuration for the heavier elements.

How do you remember how many electrons the d-orbitals can hold?

***** 10

Right. We saw that Sc, element 21, has a 3d1 4s2 configuration. What would IRON, element 26, be?

***** 3d6 4s2

Correct! At what atomic number do we attain the filled 3d10 4s2 configuration?

***** 30

This corresponds to Zinc, the last of the TRANSITION series of the 4th row in the periodic table. Into what orbital does the electron in Element 31 (Gallium) go?

***** 4p

Correct - we now begin to fill up the 4p levels.
What is the configuration (outer shell only) of Element 36?!

***** 4s2 4p6

Good. This is the next "s2,p6" inert gas element, krypton (Kr). Notice that the sequence of such elements so far is:

at nos. = 2 10 18 36

Why is the gap so much greater for the Kr, the last one?

***** because d levels are filled

Very good...The 3d levels were filled here; since d-orbitals cannot exist for n=1 and n=2, the first two series of elements were shorter. What do you think the atomic number of the NEXT (after Kr) "s2p6" element would be?

***** 54

Right! This would be Xenon, 5s2 5p6.
This takes us up through Xenon, 5s2 5p6:

2	10	18	36	54
He	Ne	Ar	Kr	Xe

To get to the NEXT analogous element, 6s2 6p6, we must add not only d-electrons (5d, this time), but also 14 4f electrons. What would the atomic no. of the element with 6s2 6p6 configuration be?

***** calc 54 + 18 + 14

86.

***** 86

Right! This brings us to Radon, the last of the known s2p6 inert gas elements.
It also brings us to the end of this module...

Most of the MASS of the atom is concentrated at its center, within a body known as the ___?____.

***** nucleus

The mass of the nucleus (and thus of the atom) is due principally to two kinds of particles. What is the name of ONE of these nuclear components?

***** proton

OK, and what is the other kind of nuclear particle called?

***** nuetron

It's spelled NEUTRON.

***** neutron

Good.
The neutron and the proton have about the same __?____
(What word goes in the blank?)

***** mass

What is the approximate relative mass ("atomic weight") of the neutron and proton?

***** 1

Correct; We will take the relative masses of the proton and neutron as 1.0; the actual figures are 1.00728 (p) and 1.00866 (n). What are the UNITS in which these relative masses are expressed?

***** amu

Right - They are called atomic mass units, amu.
The neutron and proton thus have about the same mass, but they differ in what?

***** charge

+ What electric charge does the PROTON carry?

***** 1

OK, but the 1 should be preceeded by the charge SIGN. Please enter both the sign AND the number of charges.

***** +1

So the charge of the proton is +1. And what is the charge of the NEUTRON?

***** 0

Correct - The neutron carries no charge at all.
We have seen that the proton and neutron both have a mass of about 1.0 amu.

The HELIUM nucleus contains two protons and two neutrons. What is the approximate mass of the helium atom?

***** 4

You left off the UNITS of mass - called amu. Please try again.

***** 4 amu

+ Good - this means that the ATOMIC weight of He is what?

***** 4

Correct- the atomic wt of a nucleus is sometimes called its MASS NUMBER.
There is another form of helium whose nucleus contains two protons but only ONE neutron.
What is its atomic mass?

***** 3

Correct.
There are TWO kinds of He nuclei, having atomic masses of 3.0 and 4.0, respectively.
We call them He-3 and He-4 (the numbers are ordinarily written as SUPERscripts).

Atoms or nuclei having the same number of protons but differing in atomic mass are called WHAT?

***** isotopes

Right. Do you know what a NUCLIDE is? (yes or no)

***** no

NUCLIDE is a term that refers to any given kind of nucleus, having a particular number of neutrons and/or protons.
The number of protons in a nucleus defines the ATOMIC NUMBER of that nuclide. Atomic number is often designated by the symbol Z.

What is the Z-value of He-3 ?

***** 3

NO - three is the MASS NUMBER.

***** 2

And what is the Z-value of He-4?

***** 2

Good - you see then that All ISOTOPES of a given element have the same __?__.

***** mass

ISOTOPES are defined as nuclides of the same element which differ in mass, owing to varying numbers of neutrons. The atomic numbers of two isotopes of a given element will be the same. Now answer.

***** Z

Are He-3 and H-1 isotopes?

***** no

Are He-3 and H-3 isotopes?

***** no

He-3 and H-3 have the same __?__.

***** mass number

Both nuclides have the same MASS NUMBER. Such nuclides are called ISOBARS. Can a pair of isobars have the same value of Z?

***** no

Certainly not; if two nuclides have the same MASS and the same Z, they also must have the same number of neutrons; they will thus be IDENTICAL nuclides. The term "isobars" only applies to DIFFERENT nuclides with a common mass number.
The MASS NUMBER of a nuclide is designated by A; it is the sum of the ATOMIC NUMBER Z and the NEUTRON NUMBER N.

What is the mass number of the nuclide of CARBON (at no = 6), containing 6 neutrons?

***** 12

Correct - this is designated C-12 ("carbon-12").
What is the NEUTRON NUMBER of Ar-40? (The atomic no. of Argon is 18)

***** 22

Good. The nuclides Na-23 and Na-24 have the same values of __?__
(Answer A , N , or Z)

***** Z

Correct; isotopes of the same element always must have the same Z, since Z defines the element NAME.
For two nuclides to have the same ELEMENT SYMBOL, what must be the same? (A, N, or Z)

***** Z

Right - the atomic number controls the NAME of the nuclide, and hence of the element.

c04: RELATIVE WEIGHTS OF ATOMS AND THE ATOMIC WEIGHT SCALE

The mass of a carbon atom is 1.99E-23 g. An atom of SULFUR weighs 5.32E-23 g.
Thus an atom of S is ___?___ times heavier than an atom of C.

***** calc 5.32/1.99

2.6733668

***** 2.67

Correct! Let's call the mass of the C atom 12.00 on an arbitrary scale. What is the mass of the S atom on this same scale?

***** calc 2.67 x 12

32.04

***** 32.0

You just calculated that the S atom has 2.68 times the mass of the C atom. If the relative mass of the C atom is set at 12.00, what will be the relative mass of the S atom?

***** 32

Exactly! The mass of the iron (Fe) atom is 9.27E-23 g. How many times heavier than this is the atom of carbon (mass = 1.99E-23 g.)?

***** calc 9.27/1.99

4.6582914

***** 4.67

Good. If the mass of the IRON atom (Fe) is 9.27E-23 g., what is its mass relative to C = 12.00?

***** calc 4.66 x 9.27

43.1982

***** 43.2 e-23g

Not correct;
What is the ratio of the mass of an Fe atom to that of a C atom, as calculated above?

***** 4.66

OK, a Fe atom weighs 4.66 times as much as a C atom. Now if we call the relative weight of a C atom "12", then what will be the relative weight of the Fe atom, on the same scale?

***** calc 12 x 4.66

55.92

***** 55.9

An atom of H-1, the common isotope of the lightest element, hydrogen, weighs 1.67E-24 g. What is its relative mass on the scale of C (1.99E-23 g) = 12.00?

***** calc 19.9/1.67

11.9161676

***** calc (1.67/19.9) x 12.00

1.007034

***** 1.01

Very good. One of the heaviest atoms is lead (Pb), 3.44E-22 g. What would be its weight relative to that of C = 12.00 (1.99E-23 g) ?

***** calc 12 x (34.4/1.99)

207.4371852

***** 207

Good. Because the masses of individual atoms are so extremely small, it is convenient to speak of their RELATIVE weights, on a scale such that the lightest atom has a relative weight of about 1, and the heaviest about 250.

These relative weights are often called ATOMIC WEIGHTS.

Upon which atom is the atomic weight scale based?

***** carbon

Well almost....
The atomic weight scale is based on carbon-12 (the principal isotope of C), having a relative weight of exactly 12.0000.
Atomic weights, being relative weights, can be thought of as RATIOS; they are therefore DIMENSIONLESS and need carry no units.

Each "unit" on the atomic weight scale corresponds to a real weight of 1/12 the mass of a C-12 atom. This weight (1.66E-24 g) is called the ATOMIC MASS UNIT (amu).
Use this value to find the actual mass, in grams, of a carbon atom.

***** calc 12 x 1.66

19.92

***** 19.9 E-24 g

Certainly; We have (12 amu) x (1.66 E-24 g/amu) = 19.9 E-24 g.
Use the value 1 amu = 1.66 E-24 g to find the actual mass, in grams, of an atom of nitrogen (at wt = 14.0).

The atomic weight of BROMINE (Br) is 79.9; what would be the weight of an average Br atom, expressed in amu's?

***** 79.9 amu

Exactly! What is the mass in grams, of the atom of ARSENIC ?
(at wt of As = 74.9; 1 amu = 1.66 E-24 g)

***** calc 1.66 x 74.9

124.334

***** 1.24 E-22 g

Fine. You should see, now, that the ATOMIC WEIGHT of an element is strictly proportional to the WEIGHT OF THE ATOM of the element; atomic weights can therefore be used to directly compare atoms on a weight-for weight basis. For example:
What is the RATIO of the masses of the atoms of BROMINE and MAGNESIUM?
(at wts: Br = 79.9, Mg = 24.3)

***** calc 79.9/24.3

3.2880658

***** 3.29

Good. The mass of the chromium (Cr) atom (atomic weight = 52.00) is 8.63 E-23 g.
What is the weight, in grams, of the atom of strontium?
(at wt of Sr = 87.62).

***** calc (87.62/52) x 8.63

14.54155

***** 14.5 E-23 g

Very good.

Suppose I have equal weights (10 g, say) of carbon (at wt = 12.0) and of oxygen (at wt = 16.0). In this sample there are:
1= more C atoms than O atoms;
2 = more O atoms than C atoms;
3 = equal nos. of C and O atoms.

Choosean answer and enter its number...

***** 1

Certainly! So in comparingequal MASSES of atoms of different atomic number, the atoms with the ____________ atomic number will be present in greater abundance.
(Answer h (higher) or l (lower))

***** l

Right! Which weighs MORE? 3 atoms of SILICON (Si, at wt = 28.1) or 2 atoms of CHLORINE (Cl, at wt = 35.5) ?
(Answer Cl, Si, or ns = not sure)

***** si

Correct; 3 x 28.1 is more than 2 x 35.5.

If we know the atomic weight of one element and the weights of this element and of another that form a binary compound of known formula, we can determine the atomic weight of the other element.

Suppose that 13.0 grams of element X combines with 7.12 grams of element Y to form a compound whose formula is XY (i.e., equal numbers of X and Y atoms). If the atomic weight of X is 58.7, what is the atomic weight of the element Y?
(ask for help if you get stuck)

***** help

In the compound XY, we have equal numbers of t he two kinds of atoms; call this number N. How much do N atoms of element X weigh ?

***** 13 g

OK, N atoms of X weigh 13.0 g.
And what do N atoms of Y weigh ?

***** 7.12 g

OK, so what is the ratio of the weight of Y to the weight of X in the compound?

***** calc 7.12/13

0.5476923

***** .548

Good. Now the relative weights of the two atoms must also have this same ratio, since the formula XY means we are comparing them on a 1-to-1 basis. Atom X has an atomic weight of 58.7. What is the atomic weight of atom Y?

***** calc .548 x 58.7

32.1676

***** 32.2

Right! Once again...

10.0 g of another element Q were heated with element R to form 20.7 g of a compound whose formula is known to be QR. The atomic weight of Q is 69.7. What is the atomic weight of R?
(work this out using CALC, and enter your answer.)

***** calc (10.7/10) x 69.7

74.579

***** 74.6

Great!

This is the end of the module... You may now either sign off or if you wish to continue with another module type 'other'.

*****