

FUNDAMENTAL CALCULATIONS WITH THE MOLE

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ABSTRACT

In this paper fundamental calculations are distinguished from applied calculations with respect to the mole concept. Ten fundamental calculations are discussed and a teaching model proposed. The use made of these ten fundamental calculations in fourteen chemistry textbooks recently or currently in use in Australian secondary schools is reported and discussed.

FUNDAMENTAL/APPLIED CALCULATIONS

The variety of calculations involving the mole expected in senior chemistry courses has been classified by Gower et al, (1977, a) and Gilchrist (1982), see Figures 1 and 2. The two classification schemes are effectively identical in terms of the content areas they cover. Only some of these calculations, however, make use exclusively of the theoretical concepts underlying the mole as reported by Gower *et al.* (1977, b). These theoretical concepts were discussed by the present author in a previous paper (deBerg, 1985). For the present purpose, fundamental calculations are those using exclusively these theoretical concepts, and applied calculations are those referring to calculations using chemical equations, electrochemistry, gas law chemistry, solution chemistry and so on as shown in Figure 3. Fundamental calculations refer, then, to processes which involve conversions between moles, mass, and number of particles.

1. Calculation of percentage composition from formula
2. Experimental determination of empirical formulae
3. Gas volume calculations
4. Calculations involving Avogadro's number
5. Solution concentration calculations
6. Calculations from equations
7. Electrolysis calculations
8. Titration calculations

FIGURE 1: Eight basic types of calculations involving the mole at O level (after Gower et al, 58, 1977)

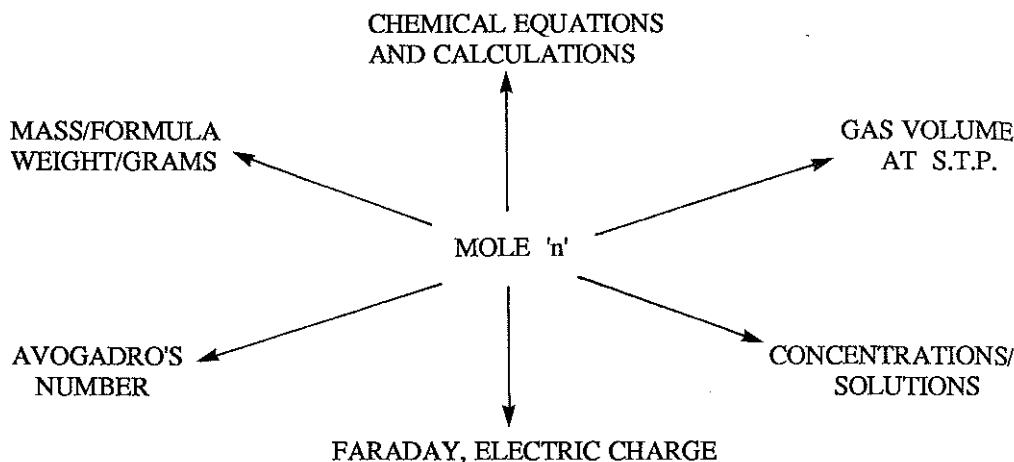


FIGURE 2: Themes of the Mole in Introductory Chemistry Courses
(after Gilchrist, 1982)

Formulae are used in fundamental calculations only for identifying particles and for the calculation of molar mass. The determination of empirical formulae is regarded in this context as an applied calculation although I realise it could be argued to be a fundamental calculation as it uses only theoretical chemical concepts discussed previously (deBerg, 1985). However I have classified it as an applied calculation owing to the additional mathematics it requires over and above the simple scheme outlined in Figure 3.

(A) FUNDAMENTAL CALCULATIONS



$M = \text{MOLAR MASS} ; \quad N = \text{AVOGADRO'S NUMBER}$

(B) APPLIED CALCULATIONS

- Percentage composition, empirical formulae
- Gas-law calculations
- Calculations from chemical equations
- Solution chemistry
- Electrochemistry, electrolysis

FIGURE 3: Distinction between fundamental and applied calculations

I believe it is important to distinguish between fundamental and applied calculations because fundamental calculations reinforce the learning of the theoretical concepts underlying the mole while applied calculations show how broadly based the mole concept is to chemistry. In establishing a learning hierarchy for the mole concept, Griffiths, Kass and Cornish (1983) confined themselves to eight skills using the fundamental calculations described here. In fact, they distinguished between skills of a fundamental and applied nature. They argued that *"the skill chosen as the superordinate skill represents the fundamental meaning of the concept. It was considered that if a hierarchy leading to the learning of this skill could be identified, further studies might be appropriate leading to potential hierarchies in areas of application of the mole concept"* (p.641).

FUNDAMENTAL CALCULATIONS AND A TEACHING MODEL

Ten problems involving fundamental calculations using the model outlined in Figure 3 are given in Figure 4. A teaching model, based upon the given information in each problem is outlined in Figure 5. Each of the ten models corresponds to the procedure for solving examples like that given in Figure 4. For example, question 7 in Figure 4 can be solved according to the model number 7 in Figure 5. The given quantities in the enclosures of Figure 5 represent either mass, moles or number of particles and each of the steps involved represents the use of mass, moles or number of particles.

1. How many atoms in 12 gram of sulfur, S?
2. (i)How many molecules in 42 gram of oxygen, O_2 ?
(ii)How many atoms in 42 gram of oxygen, O_2 ?
3. Find the mass of 100 molecules of oxygen, O_2 ?
4. Find the mass of 50 atoms of sulfur, S?
5. Find the mass of 3 moles of sulfur atoms, S?
6. Find the mass of 2 moles of oxygen molecules, O_2 ?
7. (i)How many hydrogen atoms in 5 gram of ethylene, C_2H_4 ?
(ii)Find the mass of carbon (C) in 5 gram of ethylene, C_2H_4 ?
8. (i)Find the mass of hydrogen in 100 molecules of ethylene C_2H_4 ?
(ii)Find the number of atoms in 100 molecules of ethylene, C_2H_4 ?
9. (i)Find the mass of carbon (C) in 1.5 moles of ethylene molecules, C_2H_4 ?
(ii)Find the number of atoms in 1.5 moles of ethylene, C_2H_4 ?
10. Find the mass of ethylene that contains 4 gram of carbon?

FIGURE 4: Mole concept problems

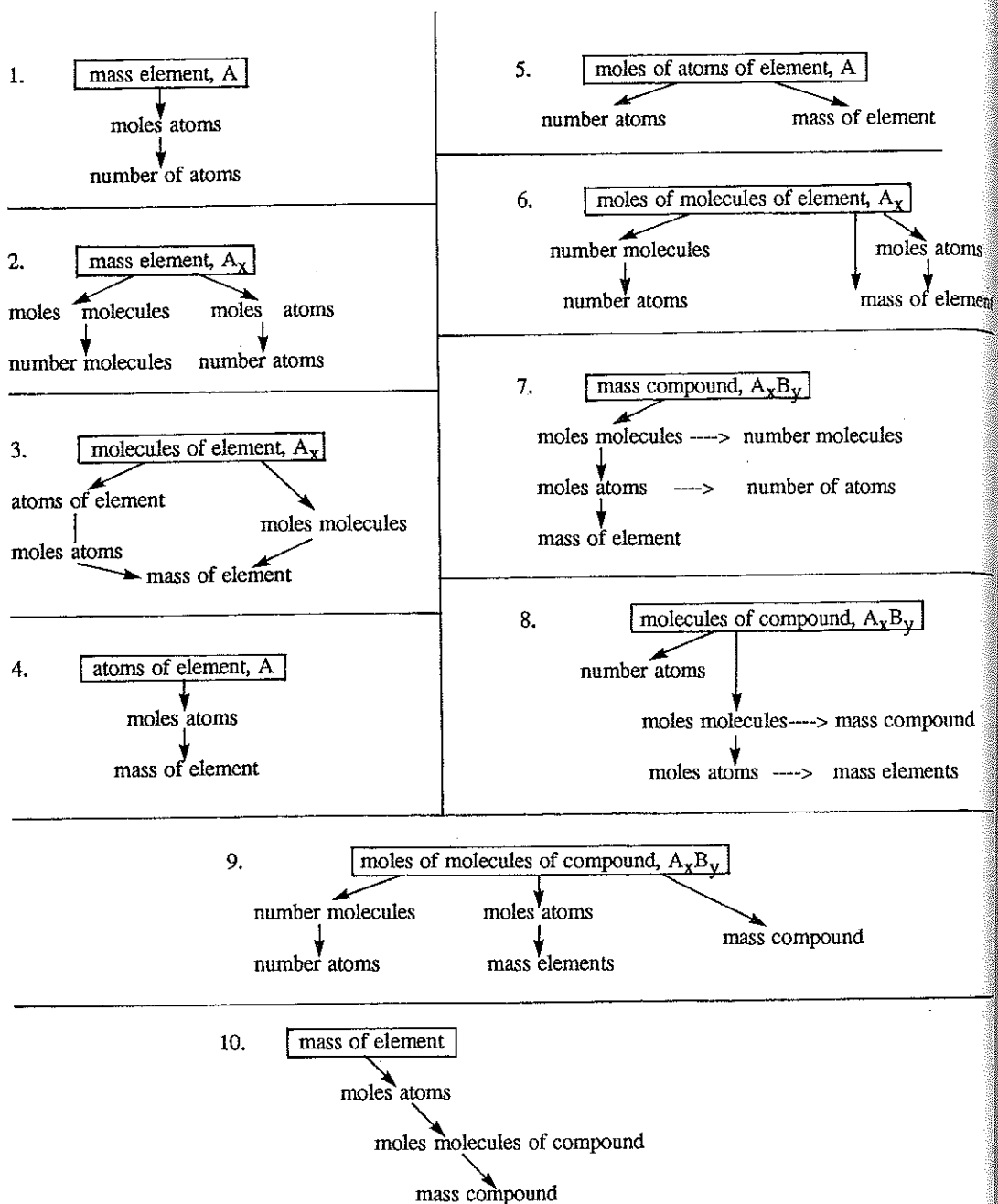
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(ii)Find the number of atoms in 1.5 moles of ethylene, C_2H_4 ?
10. Find the mass of ethylene that contains 4 gram of carbon?

FIGURE 4: Mole concept problems



KEY: x, y are positive integers

FIGURE 5: Mole concept problem solving strategies

Thus the model in Figure 3 is critical to the teaching model in Figure 5. The models in Figure 5 are not arranged as a learning hierarchy from 1--10 although my experience shows that students find model 10 more difficult than model 1. The models in Figure 5 are simply problem-solving models based upon given information as a starting point.

One of the difficulties that a teaching model like that in Figure 5 presents is that some students tend to learn each of the steps by rote and this may lead to confusion as there is a total of 38 steps in Figure 5. This can be overcome if the teaching model in Figure 5 is used in conjunction with the simple model in Figure 3. In the workbook I prepared for my chemistry students, the model in Figure 3, the teaching model in Figure 5, the examples in Figure 4 and the answers to the examples were on separate pages. The students were encouraged to use this situation for revision of work: trying problems in Figure 4, checking answers, and if incorrect checking with the corresponding model in Figure 5 until correct.

TEXTBOOK USAGE OF FUNDAMENTAL CALCULATIONS

The number of fundamental calculations which involve relationships between moles, mass and number of particles set in each text is shown in Figure 6 and Figure 7. The numbers which have similar given information to the ten samples in the model of Figure 5 are shown in the distribution of Figure 6 and the number which are identical in type to those questions in Figure 4 is shown in Figure 7. The number of problems which have similar given information to the ten samples in Figure 5 ranges from 0 to 66 and the number of problems which are identical in type to those questions in Figure 4 ranges from 0 to 17. The significant difference arises from the fact that many of the problems with similar given information to the problems in Figure 4 do not explore to the same depth as do the actual problems in Figure 4. Only half the number of texts examined have twenty or more exercises involving fundamental calculations and nine of the fourteen texts have fewer than 10 exercises identical in type to those in Figure 4. In general there is therefore a great need for textbook authors to include many more examples of a fundamental nature before exploring the applications of the mole. It is vital, judging from data in Figures 6 and 7 to increase not only the number of problems but also the breadth of coverage.

Column B of Figure 6 shows the number of problems which involve the actual number of particles. Even though the Academy text has the largest number (66) of exercises involving fundamental calculations, only five of the 66 involve work with actual number of particles. Ten of the fourteen texts have fewer than 10 problems involving the use of the actual number of particles. There has been a divergence of opinion by teachers, authors, and scientists as to whether the use of actual numbers of particles introduces unwarranted complications in the mole concept. The data presented by Griffiths *et al.* (1983) support the need to be able to calculate the actual number of particles in given mole and mass quantities of substances. They add that

"the data support the need to gain an understanding of the mole in terms of Avogadro's number of particles. This relationship had been hypothesized to exist on the grounds that for the learner it may be easier to work through an actual number of particles, even though the number is unusually large, than to think in terms of relative numbers".

I agree with these views and for this reason I included in the model of Figure 5 and problems of Figure 4 the calculation of actual number of particles. Herron *et al* (1977) also argue for the inclusion of actual numbers of particles on the basis of a theoretical analysis of the mole concept. In fact the vital link between moles and numbers of particles is lost if Avogadro's number is not associated with the definition of the mole.

F.C. with given information similar
to 1->10 in Fig 4

TEXTBOOKS	1	2	3	4	5	6	7	8	9	10	Column A	Column B
CHEM STUDY 1969	4			1		1	4	1	2		16	6
STRANKS 1975	3	2		4	1		6	1	7		25	10
COTTON 1976		1					7				8	0
PARRY 1976	3	3			2	4	3		9		25	8
MACARTNEY 1978	2		2				2		1		8	7
VERMA 1981							1		2		3	2
CARSWELL 1982											0	0
McTIGUE 1982	4	4		1	2		6		10	5	32	9
ACADEMY 1983	5	5		1	6	2	35		12		66	5
HUNTER 1983		1			1				4		8	3
JONES 1983	10	5		6	12		9		5		48	25
BEARD 1984	3	2		5	5		6	2	7	2	34	20
BROOKES 1984	4		1	3	2		10	5	5		30	21
LEWIS 1984	1						2	1			7	6

KEY: F.C. = FUNDAMENTAL CALCULATIONS
 Column A = Total F.C. Using the model of Figure 3
 Column B = Total F.C. Using the actual number of particles

FIGURE 6: Fundamental calculations across textbooks

With respect to Figure 6 the total number of fundamental calculations for a particular text may not on occasions, agree with the total across the problem types, although the two totals are very close. The reason is that there are some problems which use the number of particles --- moles --- mass model and so are fundamental but which do not identify the formula of a chemical substance as do the problems in Figure 4. For example some fundamental problems deal with marbles or stones rather than oxygen, O_2 .

F.C. identical in type to 1-10 in Fig. 4

TEXTBOOKS	1	2(i)	2(ii)	3	4	5	6	7(i)	7(ii)	8(i)	8(ii)	9(i)	9(ii)	10	TOTAL
CHEM STUDY 1969	1				1		1								3
STRANKS 1975		1			4	1						1	1		8
COTTON 1976															0
PARRY 1976	1	2				2	4								9
MACARTNEY 1978	2			2				2							6
VERMA 1981													1		1
CARSWELL 1982															0
McTIGUE 1982	3	3			1	2						1	1		11
ACADEMY 1983	1	3			1	6	2	2				2			17
HUNTER 1983			1											5	6
JONES 1983	5		1		1	7		1					1		16
BEARD 1984					5	5									10
BROOKES 1984	3			1	3	2		4							13
LEWIS 1984	1							1							2

KEY: F.C. = FUNDAMENTAL CALCULATIONS

FIGURE 7: Fundamental calculations identical in type to those in Figure 4

CONCLUSION

The distinction between fundamental and applied calculations with the mole concept has been made to show that textbooks by and large have neglected to treat fundamental calculations to the extent they might have in terms of quantity and breadth. Treatment of fundamental calculations with the breadth depicted in Figure 5 would help provide a more solid foundation in applied calculations such as solubility, acid/base and electrochemistry where the significance of formulae in terms of the particles they represent is vital.

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