

MOLECULAR NORM

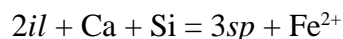
Calculation of a Molecular Norm¹

To calculate a molecular norm, follow steps 1-27 in the order given below. The following procedure assumes that weight percent oxides have already been converted to cation percent. If you are using the included worksheet, this involves: (1) calculating the cation proportions of each oxide by dividing the weight percent oxide value by the corresponding equivalent weight, (2) summing the cation proportions, and (3) dividing each cation proportion by the sum of cation proportions times 100 to convert to cation percent. Calculation of a standard molecular norm requires only 15-20 steps for most rocks.

All but four normative minerals are pure compounds with fixed chemical compositions. These four are *di*, *hy*, *ol*, and *pl* (optional); they are all solid-solution series. Three of them, *di*, *hy*, and *ol*, are ferromagnesian silicates, so it is important that the $Mg/(Mg + Fe^{2+})$ ratio be the same for all three minerals in one norm (step 17).

The term *budget* refers to the amount of a particular cation available to "make" (i.e., to be converted to) one or more normative minerals. To *make provisionally* a mineral means initially to convert all of the appropriate cation to that mineral, but with the possibility that later part of that mineral must be converted to a new mineral to satisfy a deficiency. If a budget for a cation is a negative quantity (a deficiency), too much of that cation has already been used and another mineral must be made that requires less or none of the cation. If a budget has an excess after all minerals containing that cation have been made, then the amount remaining of that cation becomes the mineral representing its pure oxide (e.g., excess Si is *q*, excess Ti is *ru*, excess Al is *c*, and excess Fe^{3+} is *hm*). Calcium is an exception to this procedure; excess Ca is made into *wo* ($CaSiO_3$).

Many steps below include chemical equations. These equations are balanced according to equivalent rather than molecular units. They are used in two ways. First, they are used to make a normative mineral from its appropriate cations (e.g., steps 2, 3, 5, 6, and 7). Second, they are used to negate a deficiency in the budget of a cation by making a new normative mineral (e.g., steps 8B, 8D, 11C, and 12B). The new mineral and the deficient cation are on the right side of the equation. The appropriate concentrations of cations or minerals on the left side of the equation must be subtracted from their respective budgets, as they are used to make the new mineral and eliminate the deficiency. For example, assume the Fe^{2+} deficiency in step 11C were -2%:

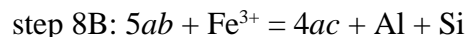


Then 6 percent *sp* would be made and 4, 2, and 2 percent *il*, Ca, and Si, respectively, are used in the process. These latter three values must be subtracted from respective budgets.

In the equations for steps 8B, 8D, 11A, and 12B, Si is on the right side, but does not represent a deficiency. In these four cases the appropriate value for Si must be added to, rather than subtracted from, the Si budget. An example is:

¹Modified from Ragland (1989)

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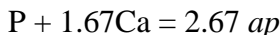


If the Al deficiency is -3 percent, then (1) 15 percent *ab* must be subtracted from provisional *ab*; (2) 3 percent Fe^{3+} must be subtracted from its budget; (3) 12 percent *ac* is made, (4) 3 percent Si must be added to its budget; and (4) the Al deficiency is eliminated.

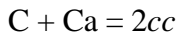
Consequently, the following generalization always holds: any calculated quantity on the right side of any equation below is a product and thus a positive quantity, whereas any quantity on the left side is a reactant and is negative. In other words, products on the right side are new minerals formed, cations to be added to existing budgets, or positive values to eliminate deficiencies. In contrast, reactants on the left side are used up making the products and must be subtracted from their respective budgets or provisional quantities.

The 27 steps are:

1. Add Mn to Fe^{2+} . If desired, add Ni to Fe^{2+} , Rb to K, Sr and Ba to Ca, Cr and V to Fe^{3+} , etc. These latter additions are seldom necessary.
2. Make *ap* from all P by:

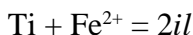


3. Make *cc* from all C by:



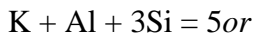
4. If desired, make pyrite (FeS_2) from S, fluorite (CaF_2) from F, halite (NaCl) from Cl, etc. Be certain to subtract necessary quantities of other involved cations (Fe^{2+} , Ca, and Na in the examples above) from their respective budgets. Since S, F, and Cl are frequently not analyzed, this step normally is not required.

5. Provisionally make *il* from all Ti by:



Generally this will also be the final amount of *il*.

6. Provisionally make *or* from all K by:



Except for extremely SiO_2 undersaturated rocks (*lc*-bearing; step 25), this will be the final *or* value.

7. Provisionally make *ab* from all Na by:

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$$\text{Na} + \text{Al} + 3\text{Si} = 5ab$$

8. Check Al budget.

- A. If excess Al (i.e., the remaining Al is a positive quantity), as is typical, continue to step 9.
 B. If deficiency (remaining Al is a negative quantity), make provisional *ac* according to:

$$5ab + \text{Fe}^{3+} = 4ac + \text{Al} + \text{Si}$$

where Al is the deficiency. In this case $an = 0$. All remaining Ca is used to make *wo*, *di*, and if necessary, *sp*.

C. Check Fe^{3+} budget. If excess, go to step 11.

D. For those rare situations in which an Fe^{3+} deficiency exists, make sodium metasilicate (*ns*; Na_2SiO_3) by:

$$8ac = 3ns + 2\text{Fe}^{3+} + 3\text{Si}$$

where 2Fe^{3+} is a deficiency. Because the rock will contain no *mt*, go to step 11 but omit steps 13-14.

9. Provisionally make *an* from all remaining Ca by:

$$\text{Ca} + 2\text{Al} + 2\text{Si} = 5an$$

10. Check Al budget again.

- A. If excess Al is present, report as *c* and continue to step 11.
 B. If deficiency, the rock is Al-undersaturated. Go to step 11.

11. Check Fe^{2+} budget.

A. If excess Fe^{2+} exists and the rock is *c*-normative from step 10A, go to step 13. If excess Fe^{2+} and the rock is Al-undersaturated, calculate available Ca by:

$$5an = \text{Ca} + 2\text{Al} + 2\text{Si}$$

where 2Al is deficiency. Subtract this value of *an* from provisional *an* (step 9) to obtain final *an*. Go to step 12. Most rocks will have excess Fe^{2+} and steps 11B-D will not be necessary.

B. If an Fe^{2+} deficiency exists and the rock is *c*-normative, then as much *il* as possible is made from original Fe^{2+} by for step 5 and excess TiO_2 is reported as *ru*. For this step and steps 11C-11D, the remaining Fe^{3+} becomes *hm*; *mt* and *fs* equal zero. Go to step 16.

C. If Fe^{2+} deficiency and rock is Al-undersaturated, calculate available Ca and final *an* using equation in step 11A. Then make *sp* according to:

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$$2il + Ca + Si = 3sp + Fe^{2+}$$

where Fe^{2+} is the deficiency. Go to step 12 but omit steps 13-15.

D. If Fe^{2+} deficiency and rock is so Al-undersaturated that no *an* exists (i.e., the rock is *ac*-normative from step 8B), then ample Ca should be available and the above equation can be used to make *sp* and eliminate the Fe^{2+} deficiency. Omit steps 13-15.

12. Check *Ca* budget.

A. If excess, make *wo* from all remaining Ca by:

$$Ca + Si = 2wo$$

B. If deficiency, which is rare, make *ru* according to:

$$3sp = ru + Ca + Si$$

where Ca is deficiency. *Di* and *wo* equal zero.

13. Provisionally make *mt* from all remaining Fe^{3+} by:

$$Fe^{3+} + 0.5Fe^{2+} = 1.5mt$$

14. Check Fe^{2+} budget again.

A. If excess, as is normal, continue to step 15.

B. If deficiency, use all available Fe^{2+} to make *mt* by:

$$Fe^{2+} + 2Fe^{3+} = 3mt$$

Report excess Fe^{3+} as *hm*. In this case *fs* = 0. Go to step 16.

15. Make *fs* from all remaining Fe^{2+} by:

$$Fe^{2+} + Si = 2fs$$

16. Make *en* from all Mg according to:

$$Mg + Si = 2en$$

17. Calculate the $Mg/(Mg + Fe^{2+})$ ratio for the ferromagnesian silicates from $en/(en+fs)$. Maintain this ratio for *di*, *hy*, and *ol* when converting to "CIPW" norms.

18. If present, combine equal percentages of *wo* and $(en + fs)$ to make *di*.

A. If no *wo*, report all $(en + fs)$ as provisional *hy*. Final *di* = 0.

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- B. If excess ($en + fs$) over wo , which is usually the case, report excess provisionally as hy ; $wo = 0$.
- C. If excess wo over ($en + fs$), report excess as wo .

19. Check Si budget.

- A. If excess, report as q and go to step 27.
- B. If deficiency and hy is available, provisionally make ol ($fo + fa$) according to:

$$4hy = 3ol + Si$$

where Si is the deficiency. $Q = 0$.

- C. If no hy is available, go to step 21. If no hy or ab are available, go to step 23.

20. Check hy budget.

- A. If excess, report as hy and go to step 27.
- B. If deficiency, use all available hy making ol and calculate new Si deficiency.

21. Attempt to eliminate this Si deficiency by provisionally making ne :

$$5ab = 3ne + 2Si$$

where $2Si$ is the deficiency. Q and $hy = 0$.

22. Check ab budget.

- A. If excess, report as ab and go to step 27.
- B. If deficiency, use all original ab making ne and calculate new Si deficiency.

23. Attempt to eliminate this Si deficiency by provisionally making lc :

$$5or = 4lc + Si$$

where Si is the deficiency. Q , hy and $ab = 0$.

24. Check or budget.

- A. If excess, report as or and go to step 27.
- B. If deficiency, which is rare, use all original or making lc and calculate new Si deficiency.

25. Attempt to eliminate this Si deficiency by making kp :

$$4lc = 3kp + Si$$

where Si is the deficiency. Q , hy , ab , and $or = 0$.

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26. Check *Ic* budget.

A. If excess, report as *Ic* and go to step 27.

B. If deficiency, which is extremely rare, use all original *Ic* making *kp* and calculate new Si deficiency. One possibility at this point is to admit defeat and report this Si deficiency as negative *q*.

27. If desired, report (*ab + an*) as *pl*.

Finally, check to determine if the summation of normative minerals is within rounding error of the cation percent total. Both totals should be very close to 100.00 percent. If no mistakes are made and the chemical analysis is of a reasonably typical igneous rock, these summations normally will be within 99.9-100.1 percent.

REFERENCES

Cox, K.G., Bell, J.D., and Pankhurst, R.J., 1979, Interpretation of Igneous Rocks: London, Allen and Unwin.

Niggli, P., 1954, Rocks and Mineral Deposits: San Francisco, W.H. Freeman.

Ragland, P.C., 1989, Basic Analytical Petrology :Oxford, Oxford University Press.