

## EXPERIMENTS ON SIMPLE BINARY MINERAL SYSTEMS

**John D. Winter**

Department of Geology  
Whitman College  
Walla Walla, WA 99362  
winterj@whitman.edu

This exercise is devised to simulate a series of experimental runs in which binary mineral mixtures are melted using very high-temperature furnaces in order to determine the characteristics of mineral systems and igneous melts. Of course, natural melts are far more complex in composition, but it is surprising how much one can learn from simplified analog systems. In an experimental laboratory you begin a study by preparing mixtures of two minerals in various proportions. The minerals are ground finely and placed in a platinum crucible. Platinum (or gold) is used because of its high melting temperature and lack of contamination of the “charge” (as the sample is commonly called). The crucible is placed in the furnace and held at a specified temperature for several hours. When the “run” is over, the charge is *quickly* removed from the furnace and rapidly cooled in a stream of compressed air or occasionally in water. Any melt that may have been produced will solidify immediately as *glass*. Any minerals that may have been stable at the run temperature, will be present as crystals, either recrystallized in the solid state below the melting temperature, or imbedded in glass if some melting occurred. Several runs are repeated, using various proportions of the two starting minerals defining the system over a range of temperatures. It is also possible to determine the composition of the run products (both glass and crystalline) by cutting the charge, making a thin section, polishing the surface, and analyzing the constituents with an electron microprobe.

Using data from a series of experiments, including: 1) initial mixture composition, 2) the run temperature, 3) the phases present in the resulting charge, and 4) the composition of each phase, a **phase diagram** can be constructed. There are several types of phase diagrams, but the most common is a careful plot of temperature versus composition (a “T-X” diagram) for all phases present at equilibrium in the run products (either solid or glass/liquid) for a particular temperature.

Since many schools lack proper furnaces, and you can get a very nasty burn anyway, we will use a computer to simulate the process. The simulation is a program called MinExp, that is on the PC's in the computer lab. You will be able to perform experimental runs for 2 different mineral systems; start with “Experiment 1.” You begin the exercise by choosing the initial mineral proportions of two (unknown) minerals in a mixture. The computer crucible will handle about 1 gram of sample, so try to make your weight totals nearly equal to that number. Next pick a run temperature (between 1000°C and 1700°C should be adequate). When the run is “complete” observe the graphical representation of the crucible. The colors will represent specific phases, either a certain mineral or glass, and their approximate relative amounts. This data may be useful to you for determining your next experimental run. The computer will allow you unlimited experimental runs, an advantage not enjoyed by the experimental petrologist who must invest time and money to perform the real thing. You should do fine with 30 or so runs for each system, spread over the complete compositional range, including the pure end-members. You may quit at any time and resume later if you care to digest initial results before proceeding.

You can also analyze your run products with a mock electron microprobe, an x-ray spectroscopic instrument. This will produce a chemical analysis of each physically distinct phase in the experimental run products (crystals, or glass). Microprobes provide data with a modest degree of statistical uncertainty. Thus your analysis, typically given as weight % oxide constituents, will

probably not sum exactly to 100%. Acceptable analyses generally range between 98-102% (2% relative error). Remember that the number of components in the phase rule is the *minimum* number of chemical constituents required to comprise the various phases in the system. Our binary systems ( $C = 2$ ) are mixtures of complex mineral end-members that each contain more than one oxide. Thus you should not confuse the number of oxides with the number of components. The microprobe results include a calculation of the weight fraction ( $X_2$ ) directly from the chemical data. The clever student might guess the identities of the (common) minerals involved by noting the oxides present and their relative proportions. Use of a mineral formula calculation would help convert the oxide analyses to a mineral formula to confirm any guesses.

When you finish, plot a phase diagram for each system on graph paper with temperature as the ordinate (y-axis) and composition as the abscissa (x-axis). Composition may be expressed as  $X_2 = n_2/(n_1+n_2)$ , where  $n_1$  and  $n_2$  are the number of grams of minerals 1 and 2, respectively. Since  $(n_1 + n_2)$  is the total number of grams,  $X_2$  is commonly called the **weight fraction** of component 2. If we measured  $n_1$  and  $n_2$  in moles,  $X_2$  would be the *mole* fraction. We will use weight fractions here. Of course, in binary mixtures  $X_1 = 1 - X_2$ . For your plots, the abscissa will thus run from a value of zero (pure component #1) on the left to one (pure component #2) on the right.

For each temperature of your results, plot the composition of *each phase*, crystal or glass (=melt), that occurs in the run at that temperature. Be sure to label what each phase is as you do this (maybe use a color or symbol code). You may discover that two or more phases coexist at equilibrium under some conditions, and that such occurrences are worth searching for and concentrating in your graphs. Indeed, once you get used to the patterns, you may elect to concentrate exclusively on runs with more than one phase. Once all of your data are plotted, connect all of the points for any single phase *that coexists with any specific other phase(s)* with a solid line. In other words, draw a line through all of the points representing liquid compositions that coexist with a particular solid, and all points for solid compositions that coexist with a liquid or another solid. The connected points should produce a smooth curve for each phase. The **liquidus** is defined as the curve representing the composition of the liquid that coexists with a solid phase. If solid solution is possible, there may also be a **solidus**, which is the curve representing the composition of the solid that coexists with a liquid. These curves separate the diagram into fields. When a diagram is complete, you should be able to place your pencil point at any point on the diagram, and predict what phase or phases are stable under those T-X conditions. Label each field with a label that describes the phase or phases that would be present if your experiment were conducted at the T and X conditions appropriate to that field. You may want to use a spreadsheet to record and plot your data.

It is possible to run Excel in one window and the program in another, or use two adjacent computers. Plotting multiple points in Excel for a single temperature is a problem for most students, and it may take you some time to figure out how to do this. If you are not yet comfortable with Excel, you may want to do this one by hand. If you do use a spreadsheet, use small symbols, and make sure those representing one phase are quite distinct from those representing another.

Next look at the various fields on your diagram. Briefly write at the bottom of the diagram for each field whether the composition of any phases are temperature dependent. In other words, would the composition of a phase shift if the temperature were raised or lowered slightly? We will discuss the results in class, so make photocopies to hand in, and keep the originals for your use in class.

## Experiments on Simple Binary Mineral Systems

### NOTES TO THE INSTRUCTOR

Many students wonder how phase diagrams are determined. Most of them have the initial idea that phase diagrams are ordained by some diabolic scientific deity. I have always wanted my classes to understand that the results are strictly empirical, and are interpretations of experiments. No matter how often I tell them this, they really don't get it. So I decided to let them determine a diagram themselves. We don't have any furnaces at Whitman for doing this, and the prospect of major burns was a further deterrent, so I decided to program a computer simulation of the process. This way students can make many experimental runs quite rapidly. I chose the eutectic Di-An system and the Ab-An solid solution.

This program is a Visual Basic program that should work on any PC running Windows95. It is available from the Whitman College Anonymous FTP site:

**marcus.whitman.edu**

Username: **anonymous**

Password: **your\_email\_address**

When you are on the Whitman Server, change directories to:

**pub\winter**

and download the file Minexp.exe.

Minexp.exe is a self-extracting file that include the program MinExp and necessary data files. Copy it to an empty directory that you name as you choose and run it (usually by double-clicking it in Explorer) to extract the appropriate files. There are a few dynamic link library files (DLL extensions) that are fine in the same directory as the program. You may prefer to put them in your WINDOWS\SYSTEM directory instead, where they will be available to other programs that may require them in the future.

If there are any changes, you may fine a note about it on my web page:

<http://www.whitman.edu/Departments/Geology/WinterBio.html>

You may also address any comments to me at: [winterj@whitman.edu](mailto:winterj@whitman.edu).

A sample screen image follows. It shows choices of 0.2 grams of mineral one mixed with 0.8 grams of mineral 2 run at 1470°C. The microprobe results are shown in a window. All a student need do is plot T vs. X<sub>2</sub> for each phase.

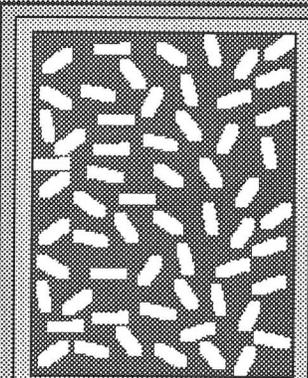
Experiment 1

Enter number of grams of mineral 1:

Enter number of grams of mineral 2:

Enter Temperature in Celsius:

Charge



glass  
 crystals

Microprobe Results

|                                    | glass | crystal |
|------------------------------------|-------|---------|
| Temperature = 1470 degrees Celsius |       |         |
| SiO <sub>2</sub>                   | 46.27 | 43.26   |
| Al <sub>2</sub> O <sub>3</sub>     | 27.65 | 36.61   |
| MgO                                | 04.51 | 00.08   |
| CaO                                | 21.50 | 20.06   |
| Total                              | 99.93 | 100.01  |
| X(2)                               | 0.75  | 1.00    |