TEACHING PHASE DIAGRAMS OF SULPHUR AND PHOSPHORUS

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Introduction

In the currently used textbooks and reference books for General Certificate of Education Advanced Level Chemistry, the phase diagrams of sulphur and phosphorus are given directly with brief explanations. However, many students are found to be not confident in the interpretation and application of phase diagrams. This lack of confidence could be due to an insufficient understanding of how the phase diagrams are constructed.

In general, students can understand how a phase diagram of a simple, single component system is established from the vapour pressure-temperature curves of the substance[1]. If students can further appreciate and apply the above-mentioned principle and relationships to the case of sulphur and phosphorus, a better comprehension of the phase diagrams will be achieved.

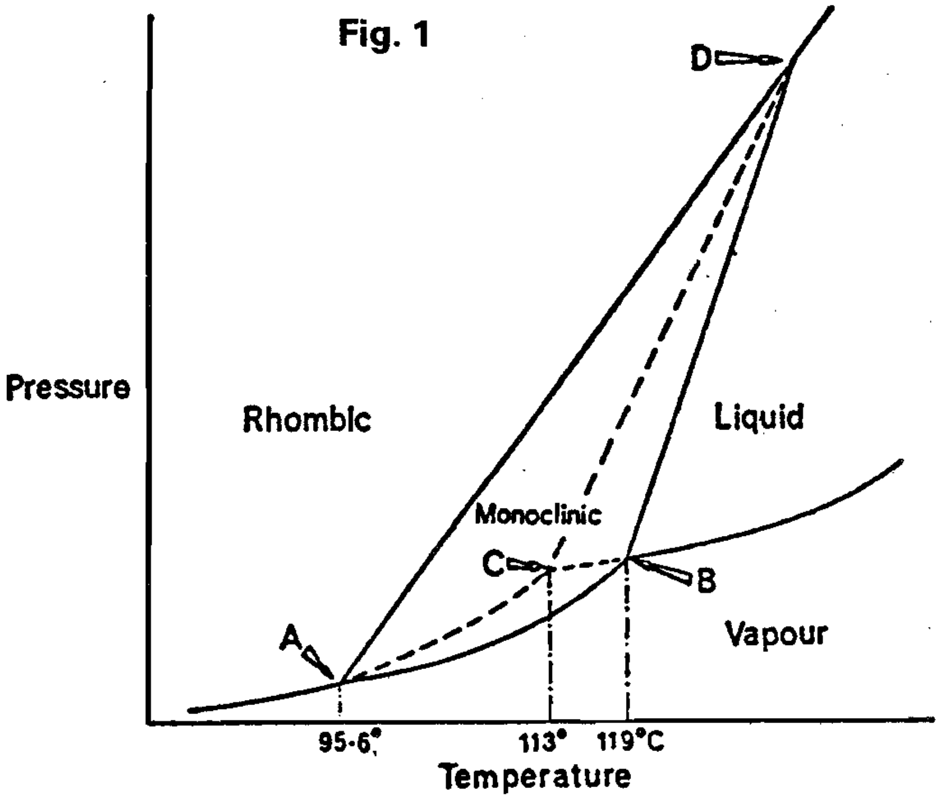
Investigating the phase diagrams of sulphur and phosphorus closely, we can recognise certain patterns. Each of these phase diagrams can be considered to include the overlapping of two simple phase diagrams of single components.

Phase Diagram of Sulphur

In the following example, we will use the phase diagram of sulphur in the form of overhead projector (OHP) transparencies to illustrate such overlapping.

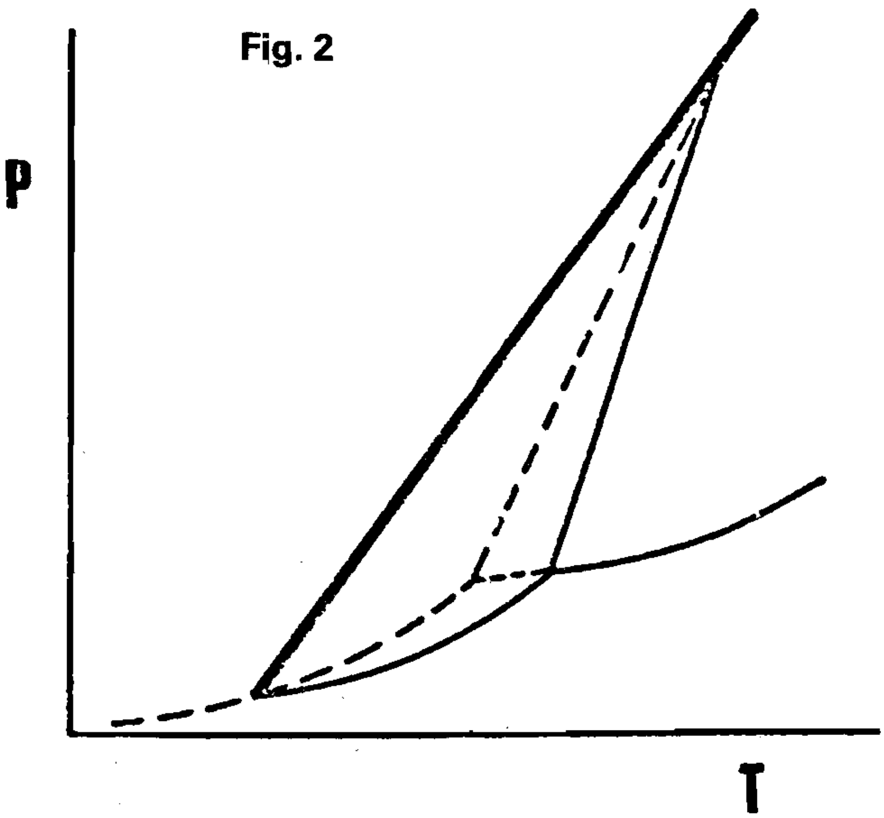
Fig. 1 shows the phase diagram of sulphur presented in ordinary text or reference books[2]. Fig. 2 is similar, except that a different presentation of the lines (eg. the dotted lines, the continuous lines and a solid dark line) is used to show the three fundamental parts of this phase diagram.

Fig. 1



Pressure–temperature diagram for sulphur

Fig. 2



The dotted lines, the continuous lines, and a solid dark line can then be transferred separately to OHP transparencies as shown below.

Fig. 3

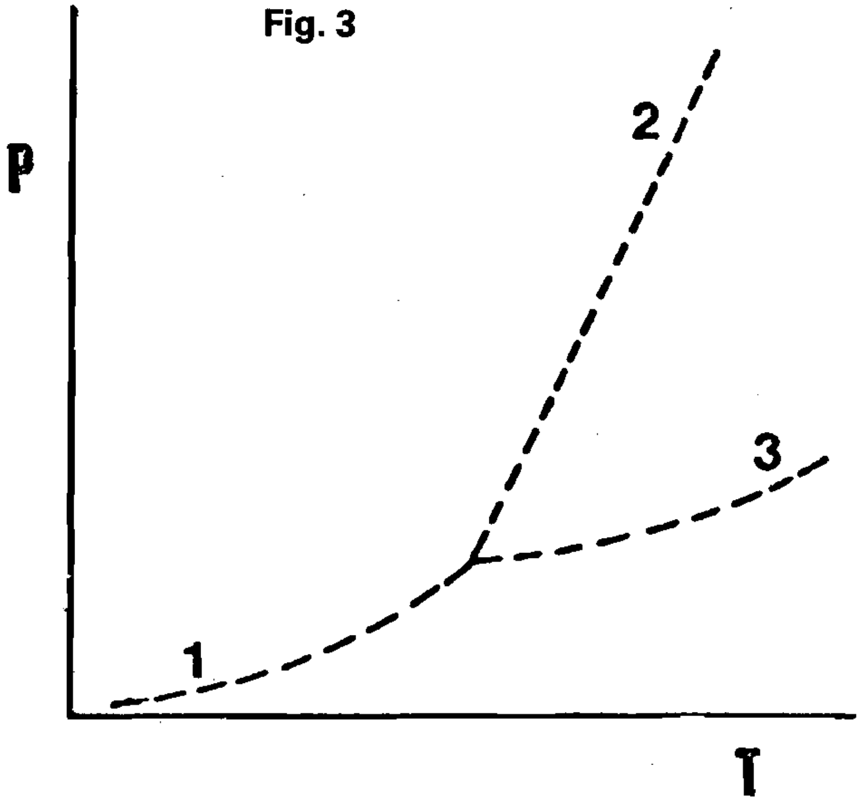


Fig. 4

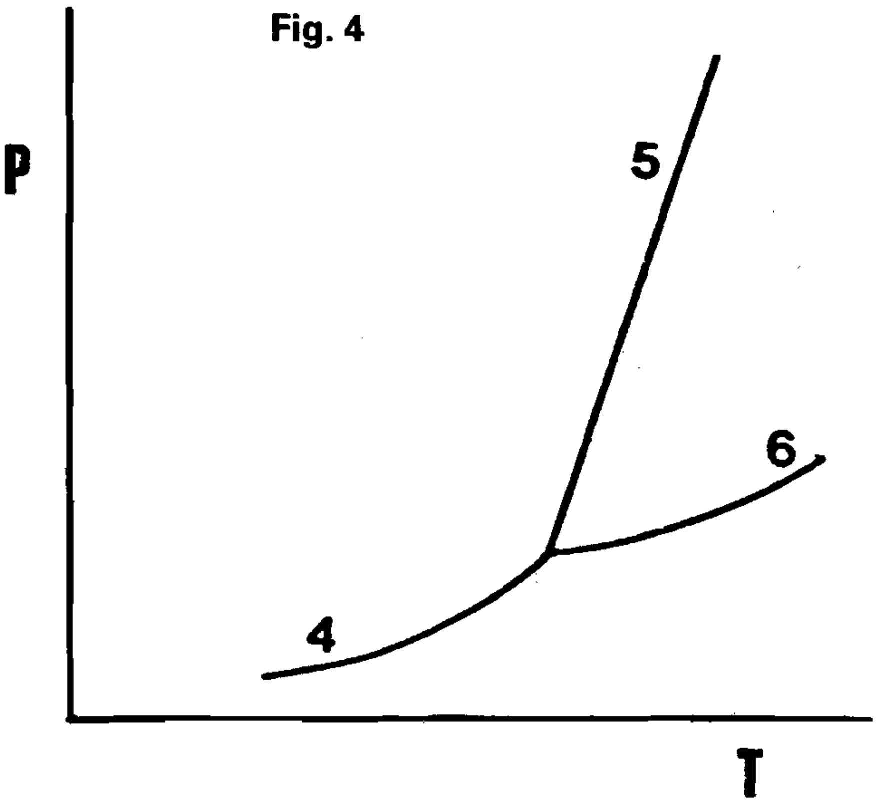
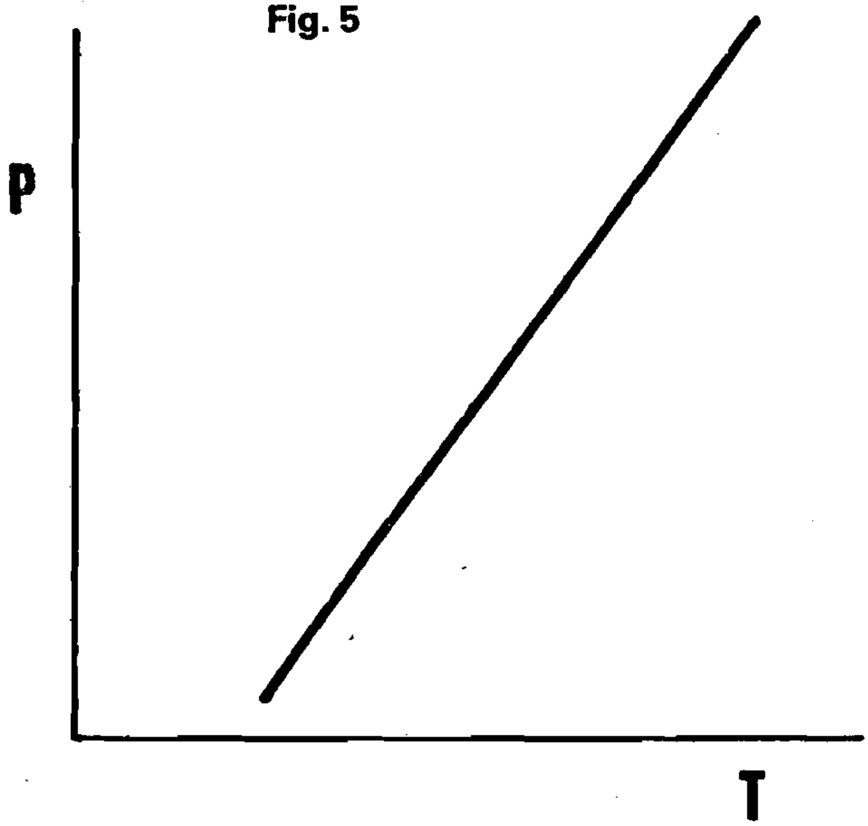


Fig. 5



Numbers assigned to the given lines as indicated in Fig. 3 and Fig. 4 are arbitrary. Actually, Fig. 3 is the simple phase diagram for α-modification and Fig. 4 is that for β-modification. Note that the solid, liquid and gaseous states of sulphur can be indicated in these diagrams as shown in Fig. 6 and Fig. 7 respectively.

Fig. 6

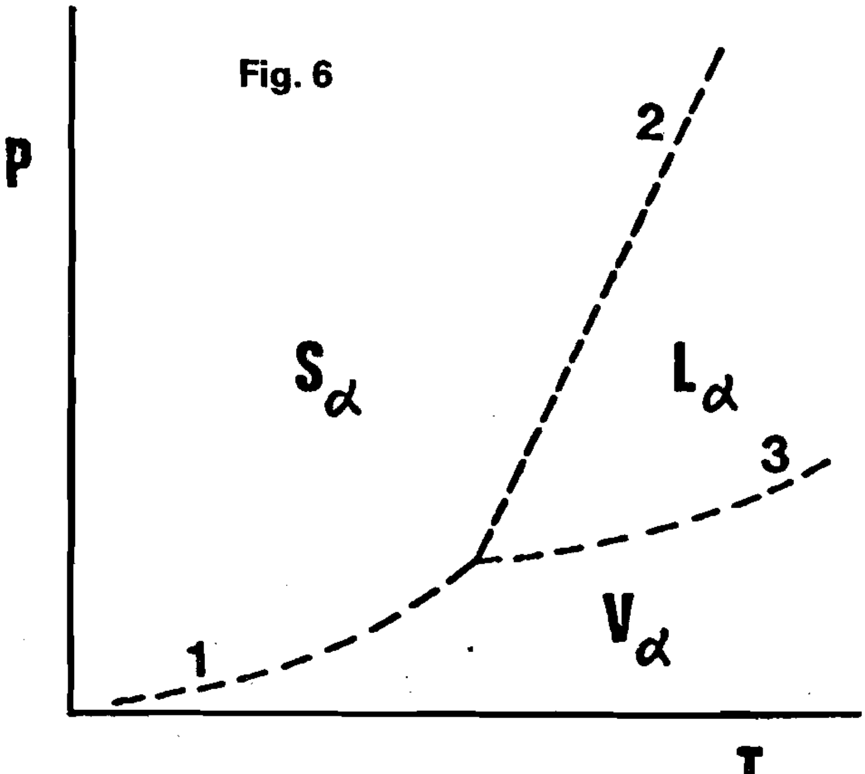
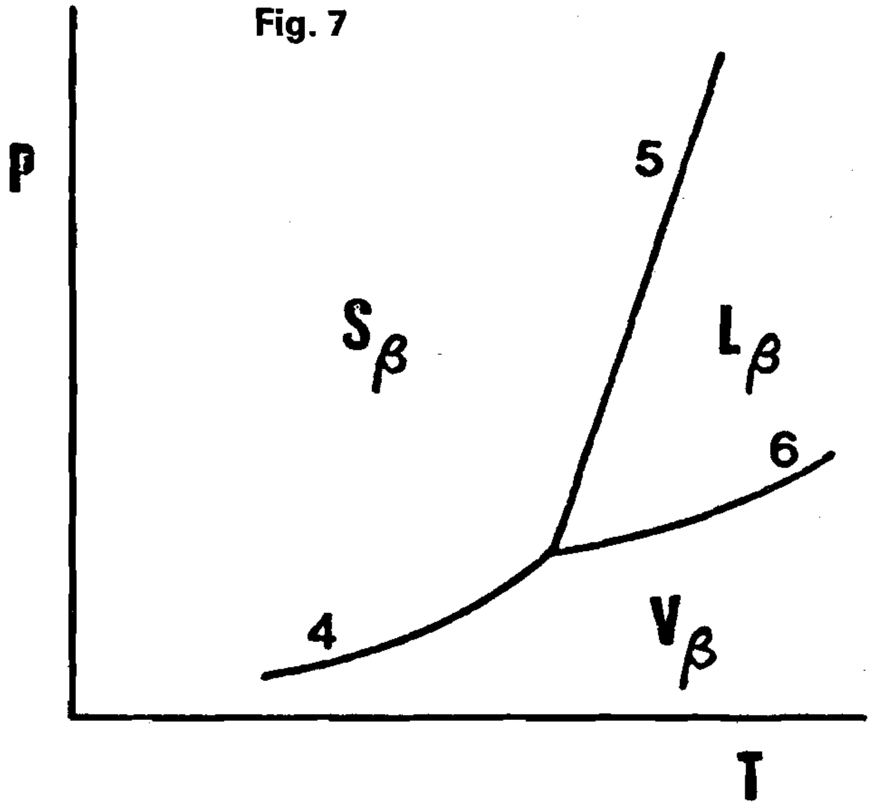


Fig. 7



In teaching the phase diagram of sulphur, we suggest the following procedure: (a) Mention the various forms of sulphur; and (b) Explain how the various equilibria are changed with the change of temperature, making use of the following conversions:

By fast heating:

$$\text{Sulphur}(\alpha) \underset{}{\overset{113^\circ C}{\rightleftharpoons}} \text{Liquid Sulphur}$$

$$\text{Sulphur}(\beta) \underset{}{\overset{119^\circ C}{\rightleftharpoons}} \text{Liquid Sulphur}$$

By slow heating:

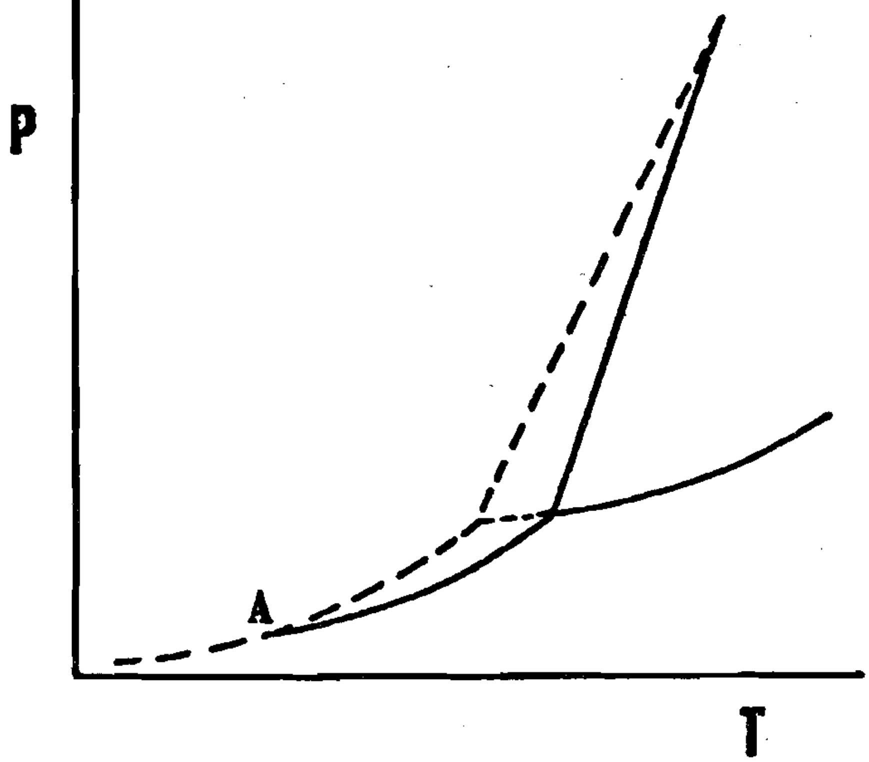
$$\text{Sulphur}(\alpha) \overset{95.6^\circ C}{\rightleftharpoons} \text{Sulphur}(\beta) \overset{119^\circ C}{\rightleftharpoons} \text{Liquid Sulphur}$$

For α-modification and β-modification, we can show to students Fig. 3 (as well as Fig. 6) and Fig. 4 (as well as Fig. 7), and remind them that for any simple substance, the pattern of either Fig. 3 or Fig. 4 should be expected.

Based on the fact that by slow heating, α-modification and β-modification are interchangeable, the two simple phase diagrams of α- and β-modifications could possibly be combined in a certain way to form a new system. Since at a high temperature (eg. higher than 119°C), only liquid sulphur will exist, the end part of the dotted line 3 and that of the continuous line 6 will coincide. If

Fig. 3 and Fig. 4 are overlayed (in the form of OHP transparencies), the following picture can then be obtained.

Fig. 8. 8



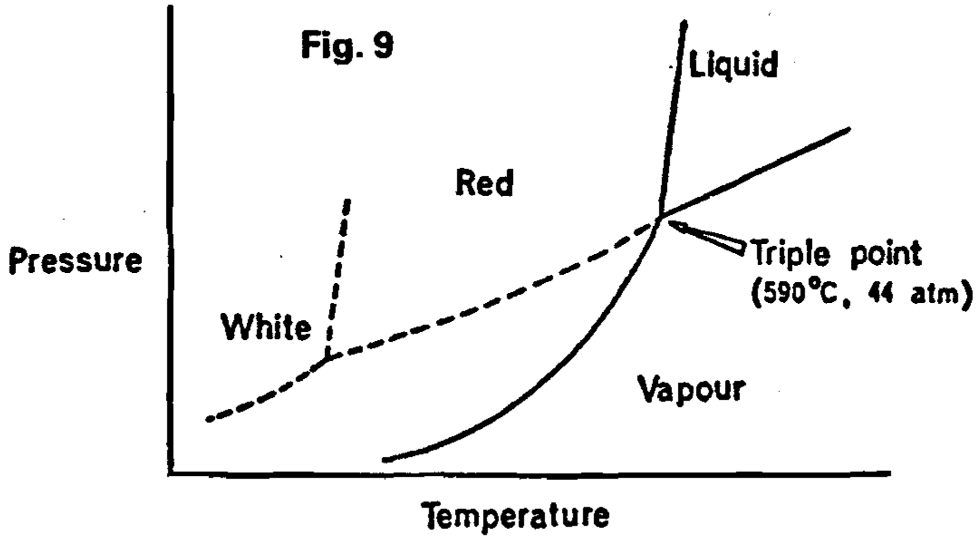
The intersection of line 1 and line 4 gives the point A, which is the conversion point from α-modification to β-modification.

The overlay of Fig. 5 on Fig. 8 shows the full picture of the sulphur phase diagram. The solid dark line shows the equilibrium of the α-modification and β-modification.

Phase Diagram of Phosphorus

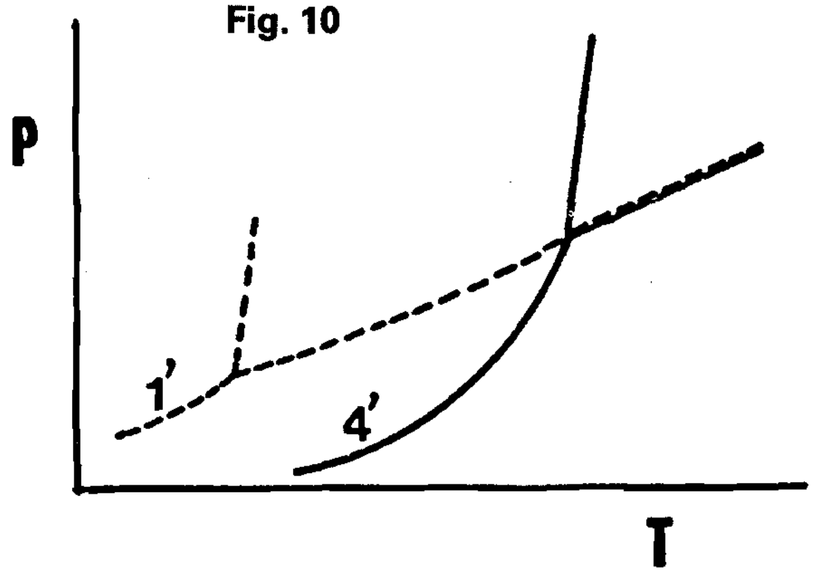
Similarly, the phase diagram of phosphorus (Fig. 9)[3] can be developed. The difference is that there is no intersection of line 1′ and line 4′ (they correspond to lines 1 and 4 respectively, in the phase diagram of sulphur), because line 1′ and line 4′ tend to be parallel (see Fig. 10).

Fig. 9



Pressure-temperature diagram for phosphorus

Fig. 10



Conclusion

These are two good examples to show students that a different overlapping of two simple phase diagrams can give a wide range of variation. Nevertheless, there are two categories, one, with intersection of lines 1 and 4, leading to an enantiotropic allotrope (eg. sulphur), and the other, without such an intersection, leading to a monotropic allotrope (eg. phosphorus).

As can be seen from the above examples, the teaching of phase diagrams can be simplified by emphasizing the understanding of some fundamental diagrams (eg. vapour pressure-temperature curves), and of the physical meaning of each point, line and area, in the diagrams. In this way, students will encounter fewer problems in the interpretation and application of more complicated phase diagrams.

Notes

1. Heys, H L, *Physical Chemistry* (5th Ed.), Harrap (1975), pp. 261–264.

2. Silcocks, C G, *Physical Chemistry for Advanced Level GCE and TEC Levels I, II and III* (3rd Ed.), MacDonald and Evans (1980), p. 105.

3. Silcocks, C G, *Physical Chemistry for Advanced Level GCE and TEC Levels I, II and III,* (3rd Ed.), MacDonald and Evans (1980), p. 106.