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# Verwiebe's "3-D" Ice phase diagram reworked

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The two dimensional phase diagrams of the various forms of ice are difficult to read and understand. A "3D" version appearing  $\approx 80$  years ago helps understanding of the phases and their interconversion into other phases.

## I. INTRODUCTION

There is no question that water (and ice, a form of water) is a fascinating substance with properties that continue to excite.

The relations between these various phases of water, i.e., steam, water vapor, liquid water, and various ices (excluding fictional ones [1]) is of continuing interest. In 1939, Frank L. Verwiebe published an article in the American Journal of Physics, volume 7, page 187, titled "A P-V-T Diagram of the Allotropic Forms of Ice" which to this day, as far as I know, contains the clearest image useful for understanding the phase relations in water; its obscurity is saddening.

In this short note, the diagram is re-interpreted and presented anew albeit in more modern terms.

## II. DETAILS

Verwiebe's drawing has been translated via Inkscape [2] allow shading of areas with the intent of highlighting one and two phase regions.

For one phase regions solid colors have been employed, while for two phase regions graded coloring has been used. These later surfaces are, of course, ruled surfaces at constant pressure and temperature with volume varying. These regions have shading, i.e., are not uniform in color density (the colors themselves were chosen virtually at random, i.e., without aesthetic sensibility),

Triple points had been indicated with circles at the three intersections where each of the three relevant phases exist. Again, the three phases differ in volume/gram as their temperatures and pressures are fixed

by virtue of representing triple points.

## III. THE RE-WORKED VERWIEBE DIAGRAM

Figure 1 has embellishments which are not in the original Verwiebe drawing, specifically the 2-phase

$\ell$ iquid  $\rightleftharpoons$  vapor

equilibrium ruled surface (evaporation or condensation), and the 2-phase

$ice(Ih, s) \rightleftharpoons$  vapor

ruled surface on the r.h.s., i.e., sublimation.

Further, ice V has been left unlabeled (it is red).

I've omitted pressure units, since I'm no longer sure about how pressure is being taught. To me, "atm" is the best unit, but I think it is no longer in favor. "mm Hg" is my second favorite, and I'm sure that it has been consigned to the proverbial trash bin. Since I'm uncomfortable with Pascals, I've left this coordinate blank.

Single phase regions are shown (for solids) as virtually vertical "planes" indicating the incompressibility of such allotropic forms of ice.

There are five triple points shown in the diagram (they have been marked with small circles at the relevant p-v-T values), but one labeled with "a", "b", and "c" is the most important triple point in the system, since it acts as a standard for temperature calibration. The actual coordinates for this triple point are: ( $t = 0.01$  C),  $\approx 0.61$  kPa (0.006 atm). The volume/gram of liquid water, "a", is smaller than the volume/gram of ice Ih, "b". As is well known, this is anomalous!

The tie-lines connecting liquid to vapor are left-truncated. Sublimation tie-lines have been omitted.

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[1] Kurt Vonnegut, Cat's Cradle.

[2] <https://inkscape.org>.

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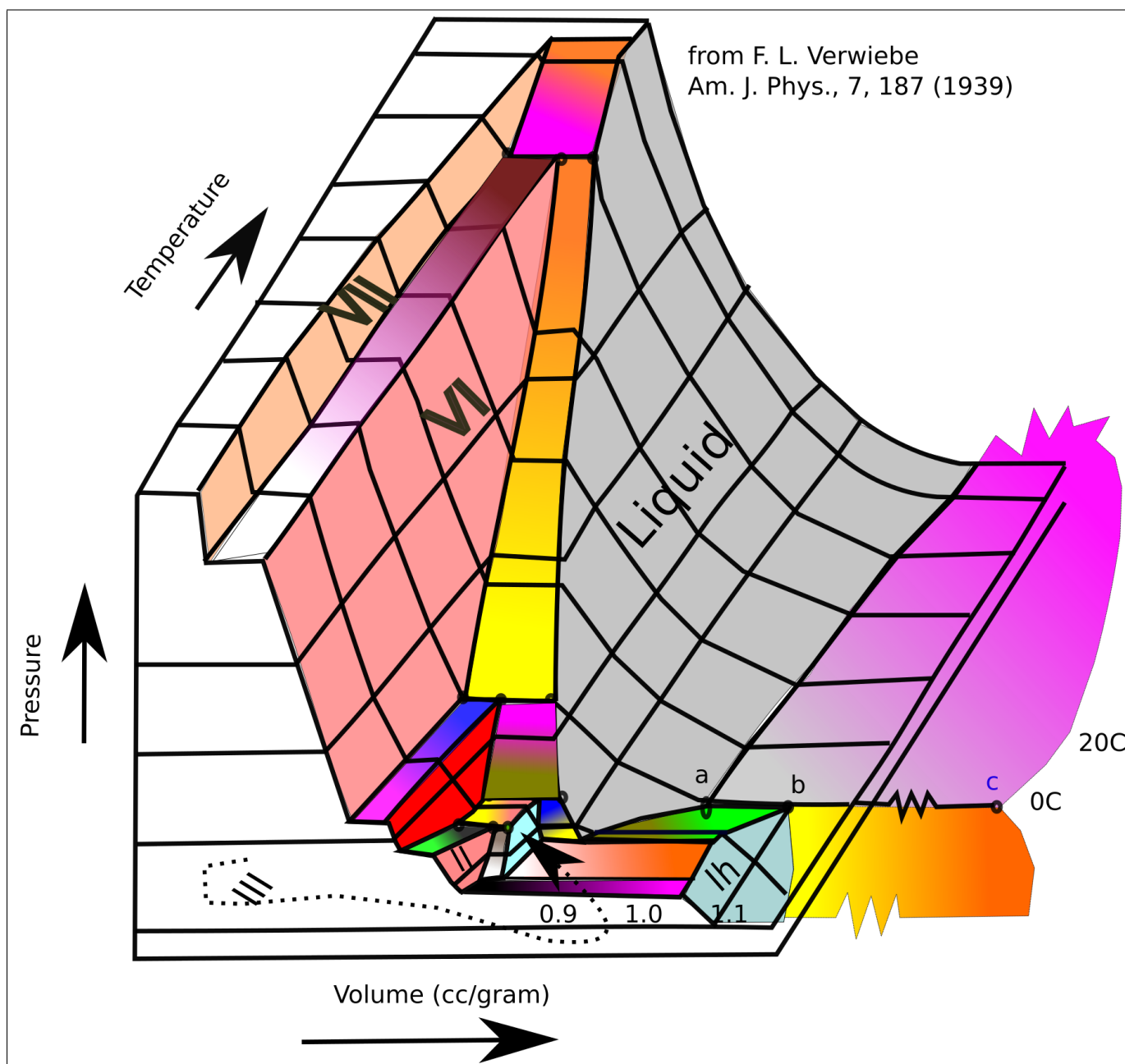


FIG. 1. The pseudo 3-dimensional rendering of the phase diagram for water. The single phase ice V label has been omitted, but the surface is colored red. The original emphasized solid ice allotropes; this version extends the diagram to include the vapor state, although the enormity of gaseous volumes mitigates against keeping the drawing to actual scale. The dense phases are separated from the gaseous phase by a broken coordinate axis.