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# The concept of sublimation – iodine as an example

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**ABSTRACT**

Sublimation is a process that is defined unequally in different textbooks and in various chemistry sources. Inexactness in defining basic concepts in chemistry can lead to alternative meanings for different people. Inconsistent explanations, then, can serve as a basis for developing misconceptions and preconceptions in latter students' education. Thus, the notion that upon heating iodine only sublimes, but does not melt is present in many chemistry textbooks, teachers lectures and, therefore, in students minds and may be considered as one of the widespread misconceptions in chemistry teaching. In this paper we offer a lecture demonstration showing the existence of all three states of iodine, supported by a short video-clip, hoping to give a contribution to the correction of misbelieves about the process of sublimation and the examples of subliming substances.

**KEYWORDS:** sublimation, misconceptions, textbooks, experiments, iodine, chemistry teaching

## Introduction

### (1) Misbelieves and misconceptions

There are several terms that refer to students' misbelieves. Some authors use the word "misconception" to define erroneous notions and others use "preconceptions" that are related to previous knowledge or arise during the course of instructions. The expression "alternative conceptions" is considered by some authors as some kind of compromise or agreement that incorporates students' faulty views during science teaching (Horton, 2004, p. 5).

The misconceptions (incorrect notions) are powerful, extremely persistent and hard to change, creating obstacles to further learning (Pabuçcu & Geban, 2006). The process of previous learning plays an important role in students' understanding and the quality of the subsequently learned concepts (Roschelle, 1995). A large number of students (and some teachers, too) believe that their established concepts are correct because they ***make sense***, meaning that they correspond to ***their*** understanding of the phenomenon in question. Consequently, when students face new information which, unlike their alternative conceptions, does not fit their previously established mental framework, they may ignore it or reject it because it seems wrong (Horton, 2004, p. 1). They attempt to solve problems in chemistry courses without real understanding of a process or a phenomenon connecting them with their previous information and concepts, which, however, may not be scientifically correct. Students can be very successful and intelligent; they may have high grades, but still retain certain misconceptions. Identifying the weaknesses in the concept-building is especially important during the students' first exposure to chemistry. The misconceptions they build in the early stages of their development are the most resistant to change during the subsequent instruction, the students constructing the new knowledge on a faulty basis and rearranging the new information and ideas to fit the framework of ideas they believe are correct. Thus, it is of utmost importance to identify, confront and correct different misconceptions that students have. The knowledge of students' misconceptions is helpful in deciding where to start and how to continue teaching.

### (2) Subliming substances

It is interesting (but also disturbing) that some of the basic concepts and terms used in the chemistry education from the earliest stages up to the university level are not properly, precisely and unequivocally defined and seem to have different meanings for different people. Rather surprisingly, the concepts of *sublimation* and *subliming substance* seem to fall into this category.

The IUPAC terminology compendium (McNaught & Wilkinson, 1997) defines sublimation as "the direct transition of a solid to a vapor without passing through a liquid phase. Example: The transition of solid $CO_2$ to $CO_2$ vapor." If *this* is the *complete* definition of it and has no limitations, its microscopic meaning would simply be **passing of molecules from a solid substance to the gaseous state of that substance**. Thus it would be completely analogous to *evaporation* – passing of molecules from the liquid state/phase of the substance to its

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gaseous state. It would be applicable to *any* solid, at any pressure or any temperature above 0 K, the possible differences being only *quantitative* and dependent on the vapor pressure of the solid in question. Indeed, such a broad (and loose) definition of sublimation is widely found in textbooks and other sources of chemical information. For example, the definition in a standard science textbook (Trefil & Hazen, 2000) is that "some solids may transform directly to the gaseous state by *sublimation*", the term "solid" clearly implying a *substance* and this makes the things to become more complicated.[1]

When examples of *subliming* ***substances*** are considered, the most usually quoted ones are dry ice (solid carbon dioxide), iodine and naphthalene. Thus, in a classical chemistry textbook (Choppin & Jaffe, 1965) it is stated that: "The transition directly from solid to gas is known as *sublimation*. Carbon dioxide is an example of a substance that sublimes (and) … iodine is another example." In the Chang's book C*hemistry* (Chang, 1990) naphthalene and iodine are given as examples of volatile solids which may be in equilibrium with their vapors and, by implication, can be considered as subliming substances.

On the other hand, many articles can be found (*Wisconsin State Journal*, 2010; Habby, 2011; *Wikipedia*, 2011; Silberberg, 2006), about the process of sublimation of *snow* and *ice* which sublime, albeit slowly, below the melting-point temperature. This phenomenon is operative for example when linen are hung wet outdoors in freezing weather to be retrieved dry at a later time. The loss of snow from a snowfield during a cold spell is often caused by sunshine acting directly on the outer layers of the snow. Ablation is a process which includes sublimation and erosive wear of glacier ice. The snow sublimes through a process that is similar to evaporation. In fact, whenever there is an interface of air and water (either liquid or solid), the $H_2O$ molecules will have some tendency, more or less pronounced, to leave the condensed phase and the processes of water evaporation and sublimation are observable at any temperature. Clearly, this is nothing new or spectacular but we do not think of water as a typical example of a *subliming substance* since ordinarily ice first melts and then vaporizes.

In fact, depending on the properties of a given solid in question, only a few substances will readily sublime *under ordinary laboratory conditions* without ***ever*** passing through the liquid state. Solid carbon dioxide (dry ice), with its triple point in the phase diagram lying above 1 bar, is the typical example of such a behavior. At ordinary atmospheric pressure (i.e. at atmospheric pressure close to 1 bar) dry ice *can not* be melted. Another (albeit somewhat exotic, radioactive and very poisonous) substance with analogous properties is uranium hexafluoride with its triple point being $\approx$ 337 K and 1.5 bar.

Other solid substances, especially if they are highly volatile (characterized by their high vapor pressure), may sublime at room temperature but if the temperature is carefully increased, it is possible to melt them. **Iodine**, for example, at ordinary pressures *can* exist in the liquid state at temperatures in the interval from 113.6 to 184.4 °C (Petrucci, 2001). Our relatively simple experiment (described below) provides an impressive demonstration for this. It should be noted that the triple point of iodine is found *below* 1 bar (113.5 °C; 12.07 kPa) and such is also the case with naphthalene (80.25 °C; 1.0 kPa) or camphor (180.1 °C; 51.44 kPa), the latter compound being sometimes quoted, together with carbon dioxide, iodine and naphthalene, as a typical substance that sublimes.

The examples given above lead to the necessity to set up a more *restrictive* meaning of the concept of sublimation with a view to the definition of a subliming substance.[2] In our view, *sublimation* (in the restrictive mining of the term) would be a process where a solid substance on heating, **at ordinary atmospheric pressure**, undergoes a solid $\longrightarrow$ gas transition directly, without first melting, i.e. without the appearance of a liquid phase. The typical example obeying such a restrictive definition would be solid $CO_2$ but *not* iodine, naphthalene or camphor. We believe that at the high-school level only this restrictive definition is suitable (perhaps sometimes accompanied by a warning that a more precise definition exists). It is the latter definition that is dealt with in the present paper and this (in our view, as already pointed out), should be used in the general pedagogical practice.

Unfortunately, the broad rather than the restrictive definition is firmly entrenched in the minds of students, teachers, textbook authors and practicing chemists. Thus, if asked to name a subliming substance, iodine is very likely to appear as one of the preferred examples.

## The problem: a lasting misconception

One of the widely spread misconceptions is that about the *sublimation* of iodine. There are too many people (Chemical forums, 2005; Trach, 2003) believing that, even at standard pressure, iodine can *only sublime and not be melted*, and such notions are indeed found in many books, including several textbooks that are in use in Macedonia. Thus, at two instances (Aleksovska & Stojanovski, 2005; Doneva-Atanasoska, Aleksovska & Malinkova, 2002) the authors say that *upon heating* iodine transforms directly from a solid to a gaseous state ("without being liquefied"), while in a textbook for the 1st year of reformed gymnasium (Cvetković, 2002) the defini-

[1] The definition of evaporation (McNaught & Wilkinson, 1997) is "The physical process by which a liquid substance is converted to a gas or vapour" where there is an explicit mention of "a … substance".

[2] An alternative would be to coin a new term for the special type of sublimation that is analogous to boiling rather than to evaporation. This will be discussed in one of our forthcoming contributions.

**Figure 1.** Iodine (both solid and vapor) in a hermetically closed vessel.

tion and the examples given are similar, but heating is not mentioned explicitly.

Consequently, many teachers honestly believe that iodine is a typical example of a substance that, irrespective of the experimental conditions, sublimes without being melted, being ignorant, consciously or subconsciously, of the incompleteness in their understanding of the meaning of the term. Thus, in their lectures instructors loosely use the term "sublimation" and the imprecise definition of sublimation is instilled in the student's minds as a truism. The notion is strengthened by the fact that students could have seen the demonstration in which iodine crystals are heated to release violet vapor and it has been explained in terms of sublimation (Kotz, Treichel & Townsend, 2009). In such a case, they have a false impression that a liquid is not produced since the deep color of the iodine vapor that is quickly released often masks the appearance of the liquid phase (Yahoo answers, 2009). In fact, iodine vapor can be seen even without heating. If, namely, iodine crystals are put in a test tube (or better, sealed into a larger vessel), not very intense violet vapor *can* be observed inside the ampoule almost instantaneously (Figure 1) this being indeed associated with the sublimation of solid iodine due to its relatively high vapour pressure.

Unfortunately, the combined effect of the instructor's teaching and the student's personal experience (imprecise and incomplete as it turns out to be) forms a basis for a misconception that is readily accepted by the students. They "know" that solid iodine can only sublime and can not be first melted and in their mind this is final.

However, as mentioned above, it is a known fact that at atmospheric pressure iodine is liquid in the interval from 113.5 to 184.4 °C meaning that iodine first melts and *then* vaporizes rather than "skipping" the liquid phase (*Wikipedia*, 2011; Heilman, 2004). Indeed, as discussed below, *it is* possible to obtain liquid iodine at atmospheric pressure by controlling the temperature at just above the melting point of iodine and **see** the melt. This is not new at all. There are at least two offered demonstrations (Summerlin, Borgford & Ealy, 1987; Najdoski & Petruševski, 2002) in the literature devoted to chemical lecture experiments and demonstrations where the authors offered suitable experiments to demonstrate the existence of liquid iodine at atmospheric pressure. Now we try to strengthen the notion by including a short video clip. In the latter decision, we were governed by the common saying that "a picture substitutes a thousand words". Consequently a video clip can indeed substitute (even literally) a thousand pictures, although the effect of live experiments is beyond doubt even stronger. It is a pity that all too many instructors rely heavily on available video material prepared by others instead of performing real experiments (Petruševski, Stojanovska & Šoptrajanov, 2009) but that is a fact. Therefore, if the material we offer here helps in fighting the misconception about iodine only subliming, but not melting upon heating, then it will completely serve its purpose.

## Confronting the misconception: the offered experiment and video clip

The most effective chemistry tool among numerous teaching strategies and techniques used to reduce misconceptions in science teaching is an *experiment* or a *demonstration*. Using demonstration (or experiment), one can, more or less, easily test his/hers assumptions and confirm the correctness (or falseness) of the proposed hypothesis. Demonstrations/experiments are an inextricable component of chemistry teaching and, if properly preformed, lead to a development of an active and creative thinking.

As a means for fighting the discussed misconception, a laboratory demonstration was devised,[3] in which appropriate apparatus and careful control of the temperature just above the melting point of iodine is employed.

The experimental setup (Figure 2) for this experiment includes a beaker filled with glycerol, a thermometer, a heater and a narrow test tube containing iodine crystals. The test tube may be sealed (for safer work), but this is not a necessary precondition for performing the demonstration. Glycerol has been chosen for this purpose because, on one hand, its boiling point (290 °C) is much higher than the melting point of iodine (113.5 °C), and on the other, glycerol is a colorless liquid unlike oil that has previously been used (Summerlin, Borgford & Ealy, 1987). The glycerol bath is heated to approximately 140 °C. As temperature passes over the melting point of iodine, it can be clearly seen that iodine crystals begin to melt and, after some time, flow along the test tube inner walls when the tube is tilted (Figure 3). The process of iodine melting can be easily noticed on the video clip prepared for this demonstration. The first part of the clip shows the behavior of iodine crystals in a test tube and is to be compared with

[3] It is based on modifications of two demonstrations proposed earlier (Summerlin, Borgford & Ealy, 1987; Najdoski & Petruševski, 2002).

**Figure 2.** Melting of iodine, the experimental setup: digital thermometer (left), test-tube with iodine (middle) and the glycerol bath with the thermocouple (right).

the behavior of the liquid iodine (obtained a few minutes later).

## Conclusion

The result of the experiment (or, for that matter, the video clip) shows very clearly and beyond any doubt that iodine can be liquid under atmospheric pressure. This is only one example of the fact that experiments (carried out either by teachers or students) are very powerful tool in chemistry teaching. They can be used as an introductory or as a conclusion of the lesson, to verify or to explore phenomena, as well as to serve as a concept building and correcting existent misunderstandings and misconceptions students may have. Another aspect that has to be addressed at this point is caution while reading experimental procedures and performing the experiments. There are cases (one of them is dealt with in this paper) when the result of the experiment does not correspond to the summary or the explanation offered.

If no demonstration is performed, a lot of efforts might be needed to convince the students to abandon the previously learned concepts and to finally accept the new knowledge as valid and correct. Nevertheless, we should continue the search for suitable (novel or existent) ways to persuade the students and eliminate the effect of this misconception.

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**Supplementary material**: Liquid_iodine?.mpg (video clip, available at the URL http://bit.ly/A6F1GS)

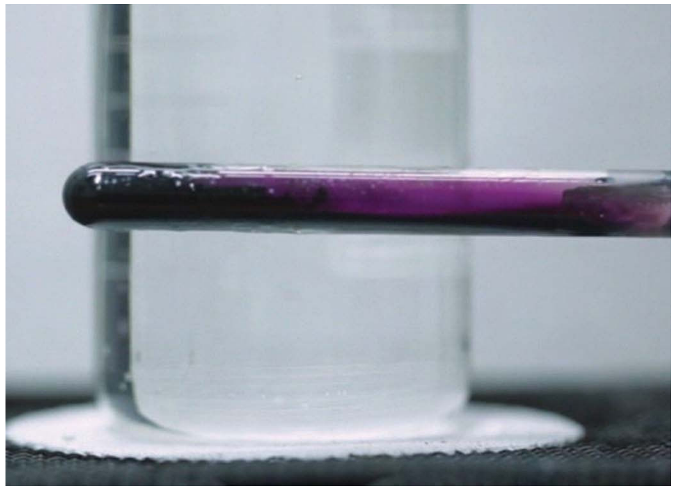

**Figure 3.** Liquid iodine is easily seen in the test-tube. You can watch a video of the melting process at the following URL: http://bit.ly/A6F1GS

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