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Solubility of Xenon-133 at 37°C in Water, Saline, Olive Oil, Liquid Paraffin, Solutions of Albumin, and Blood

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ABSTRACT. The solubility of ^{133}Xe was determined at 37°C in the substances given in the title. The solubility of xenon in blood was found to follow Henry's law at pressures up to one atmosphere.

1. Introduction

In view of the considerable discrepancies between the values of the solubility of xenon reported in the literature, this work was done in order to produce from our own measurements reliable data for experimental use and comparison with published values.

2. Material

^{133}Xe was purchased from the Radiochemical Centre, Amersham. The impurity of the isotope with regard to other radioactive isotopes was, according to specifications, below 2%. The impurity consisted mainly of ^{133}Xe, besides occasional ^{131}Xe and ^{85}Kr. The data were verified by decay and spectral analysis.

Non-radioactive xenon was purchased from Dansk Ilt og Brint, Copenhagen By mass spectrography the content of xenon was found to be 99·95%, the remaining 0·05% being krypton, nitrogen, and carbon oxide, together with occasional traces of hydrogen, oxygen, and carbon dioxide.

Blood samples with different hematocrit values were prepared with heparinized blood from volunteer donors by pipetting plasma after spinning. The hematocrit values were determined by spinning the samples for 30 minutes at 1500 G.

A 20% solution of albumin was purchased from Statens Seruminstitut, Copenhagen. According to the specification, the solution was prepared by alcohol fractionation (Cohn's fraction V) and consisted of 97% albumin and 3% α and β globulin. The solution, moreover, contained 1% of glycine and 0·1% of acetyltryptophan as stabilizers besides 10 meq/l Cl^- and 100 meq/l Na^+. The solution was heat-treated (at 60°C for 10 hours).

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Liquid paraffin (heavy) and olive oil were purchased at a pharmacy. Both substances were declared to satisfy the requirements of Pharmacopoea Nordica (1966) and Pharmacopoea Danica (1948).

Distilled water was used as water standard.

The specific gravity of the substances used was taken from the literature: olive oil 0·91; liquid paraffin 0·86 – 0·90; 0·9% NaCl 1·005; plasma 1·027; erythrocytes 1·084–1·117; and albumin 1·073 (Pharmacopoea Nordica 1966, Pharmacopoea Danica 1948, Hoppe-Seyler and Tierfelder 1953, Handbook of Chemistry and Physics 1962).

3. Methods

3.1. *The solubility of ^{133}Xe in water*

An airtight vial of 2 ml was nearly half filled with distilled water. A few μCi of ^{133}Xe was added to the atmospheric air in the vial. After shaking and equilibration for 24 hours about 0·2 to 0·3 ml of the water was transferred to another capped vial of the same size, while the xenon-containing air remained in the original vial (no. 1). The transference was made by connecting the two vials through a needle, a slight negative pressure being made in vial no. 2 before the connection. The radioactivity in the two vials was determined in a well-type scintillation counter. The amounts of water and air were determined by weighing both vials empty, both vials after the water had been transferred, and the original vial filled with water. These values together with specific gravity of water at 37°C (0·995433) were employed for calculating the radioactivity per ml air and water; the Ostwald's solubility coefficient was determined as the ratio between these quantities. A correction was made for the radioactivity in the water left in vial no. 1. All manipulations were carried out at a temperature of 37°C.

3.2. *The solubility of ^{133}Xe in albumin, blood, liquid paraffin, olive oil, and isotonic saline*

The measurements were made by employing the technique described by Andersen and Ladefoged (1965): samples of the materials in question were placed in small test tubes together with a sample of distilled water in an airtight chamber containing about 100 ml atmospheric air and 0·5 to 2 μCi ^{133}Xe. Equilibration took place for 24 hours at 37°C. The samples were stirred constantly with a magnetic stirring rod. After equilibration, the samples were transferred into syringes. From the syringe about 0·1 ml of each sample was transferred into a 2 ml rubber-capped vial and counted in a scintillation counter. Weighing of the vials before and after introduction of the sample gave the weight of the sample. From these values the ratio of radioactivity per g of the material in question to radioactivity per g of water was calculated and converted into the terms of Ostwald's coefficient by use of the specific gravity and the previous determination of Ostwald's solubility coefficient in water. Other determinations of the solubility of ^{133}Xe in blood were made with the chamber filled with nitrogen and oxygen.

3.3. *The solubility of ^{133}Xe at increasing partial pressure*

These measurements were also made with the equipment described by Andersen and Ladefoged (1965). The chamber was filled with a mixture of xenon to which were added ^{133}Xe and oxygen, and the pressure in the chamber was equilibrated to atmospheric pressure. The composition of the gaseous mixture in the chamber was determined by measuring the oxygen content with the apparatus described by Scholander (1947). By duplicate determinations the error of the oxygen analysis was found to be 0·5 vol.%. The absolute solubility of ^{133}Xe in blood was also calculated from the determination of the water solubility.

4. Results

Table 1 lists the values found for Ostwald's solubility coefficient. Since the relative solubility was determined, the error of the determination of the solubility coefficient of water should be added to the errors given for all substances other than water. For comparison with the results from the literature, the partition coefficient for ^{133}Xe between the various substances and water are also given in table 1.

Table 1. Solubility and partition coefficients for ^{133}Xe in various solvents at 37°C.

Solvent	Ostwald's solubility coefficient	Partition coefficient solvent: water	Number of observations
Distilled water	0·0834 ± 0·0002	1·00	107
0·9% NaCl	0·078 ± 0·007	0·940 ± 0·008	5
Olive oil	1·79 ± 0·04	21·5 ± 0·5	8
Paraffinum liquidum (heavy)	1·96 ± 0·07	23·5 ± 0·8	8
Albumin solution 200 g/l	0·099 ± 0·003	1·19 ± 0·04	12
Plasma (saturated with air at 1 atm)	0·091 ± 0·002	1·09 ± 0·02	30
Plasma (saturated with N_2 at 1 atm)	0·090 ± 0·002	1·08 ± 0·02	36
Plasma (saturated with O_2 at 1 atm)	0·093 ± 0·002	1·12 ± 0·03	27
Erythrocytes (saturated with air at 1 atm)	0·19 ± 0·008	2·31 ± 0·09	30
Erythrocytes (saturated with N_2 at 1 atm)	0·20 ± 0·008	2·37 ± 0·10	36
Erythrocytes (saturated with O_2 at 1 atm)	0·17 ± 0·010	2·08 ± 0·13	27
Blood with hematocrit 30% (calculated from above values)	0·119	1·43	
Blood with hematocrit 40% calculated from above values)	0·129	1·55	
Blood with hematocrit 50% (calculated from above values)	0·139	1·67	

Fig. 1 shows the solubility of ^{133}Xe in erythrocytes and plasma at increasing partial pressures. At pressures within 0 to 1 atmosphere the solubility follows Henry's law. In these experiments the solubility was found to be $0{\cdot}189 \pm 0{\cdot}004$

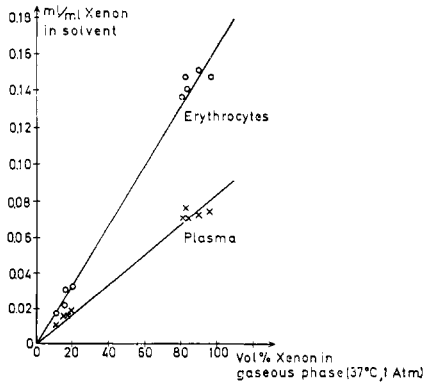

Fig. 1. Solubility of xenon at increasing partial pressure.

Table 2. Collected data from the literature on solubility of xenon in various solvents at 37°C.

Solvent	Ostwald's solubility coefficient	Partition coefficient solvent: water	Reference
Distilled water	0·097	—	Von Antropoff 1919
	0·097	—	Valentiner 1927–30
	0·074	—	Morrison and Johnstone 1954
	0·0827	—	Yeh and Peterson 1964
0·9% NaCl	0·0778	0·94	Yeh and Peterson 1964
	0·0926	—	Isbister *et al.* 1965
Olive oil	1·8532	22·4	Yeh and Peterson 1963
Plasma	—	1·45 (in g/g)	Conn 1961
	0·1028	1·11 } Water=Saline	Isbister *et al.* 1965
	—	1·14 }	Veall and Mallett 1965
	—	1·05	Andersen and Ladefoged 1965
Erythrocytes	—	3·75 (in g/g)	Conn 1961
	0·2020	2·16 } Water=Saline	Isbister *et al.* 1965
	—	2·33 }	Veall and Mallett 1965
	—	2·31	Andersen and Ladefoged 1965
Whole blood	—	2·49—2·10 (in g/g)[1]	Conn 1961
	0·1810	2·19[2]	Yeh and Peterson 1965
	—	$1{\cdot}05 + 0{\cdot}013 \times$ Hct	Andersen and Ladefoged 1965

[1] Haemoglobin 15 g/100 ml.
[2] Haemoglobin 18 g/100 ml.

in erythrocytes and $0{\cdot}089 \pm 0{\cdot}002$ in plasma. These data are not significantly different from those in table 1.

Table 2 gives the collected data on the solubility of ^{133}Xe. The table discloses considerable discrepancies between the reported determinations.

5. Discussion

The results of the present determinations are fully consistent with the data given by Yeh and Peterson (1965, table 2). On the other hand, the results show a considerable inconsistency with earlier determinations of the solubility of ^{133}Xe in water (van Antropoff 1919, Valentiner 1927; 1930, table 2) and with the values of the solubility in sodium chloride and blood recently reported by Isbister *et al.* (1965, table 2).

The values found by van Antropoff and Valentiner at different temperatures were higher than all subsequent determinations (Eucken and Hertzberg 1950, Morrison and Johnstone 1954, König 1963, Yeh and Peterson 1965), which may be explained by the possible occurrence of supersaturation in their determinations. With regard to the measurements by Isbister *et al.* (1965), these were performed by an isotope method; the counting technique used has been criticized (Gillespie 1965). As the source of error mentioned in this criticism will tend to give solubility coefficients that are too high, while the partition coefficients will be very little influenced, this source of error seems a reasonable explanation of the discrepancy between their results and the present ones.

At pressures between 0 and 1 atmosphere the solubility of ^{133}Xe was found to follow Henry's law. The same holds good of other inactive gases: helium and nitrogen (Hawkins and Schilling 1936), nitrous oxide (Siebeck 1909), though the validity of the law for nitrogen has been contested (Conant and Scott 1926).

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Résumé

La solubilité du xénon-133 à 37°C dans l'eau, solution saline, huile d'olive, paraffine liquide, solutions d'albumine et sang.

On a déterminé la solubilité du xénon-133 à 37°C dans les substances énumérées ci-haut. On a trouvé que la solubilité du xénon dans le sang obéit la loi de Henry sous pressions jusqu'à une atmosphère.

Zusammenfassung

Löslichkeit von Xenon-133 bei 37°C in Wasser, Salzlösungen, Olivenöl, flüssigem Paraffin, Albuminlösungen und Blut.

Es wird die Löslichkeit von ^{133}Xe bei 37°C in den obenangeführten Stoffen bestimmt. Es wurde gefunden, dass die Löslichkeit von Xenon im Blut das Henrygesetz bei Drucken bis zur 1 atm befolgt.

Резюме

Растворимость ксенона-133 при 37 °С в воде, солевом растворе, оливковом масле, жидком парафине, растворах альбумина и в крови.

Определялась растворимость ^{133}Xe при 37 °С в выше приведенных веществах. Оказалось, что растворимость ксенона в крови повинуется закону Генри при давлениях до одной атмосферы.

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