

and died during convulsions. Of the 19 whose convulsions ceased following chlorpromazine administration only one died during the ensuing depression while 18 recovered. Thus, of a total of 42 animals receiving 250 mg./Kg. of diphenhydramine, 32 developed symptoms requiring treatment and 28 of these recovered.

Limited studies of the effectiveness of this regimen in combating acutely toxic doses of several other antihistaminics were conducted. The protocol was unchanged, except that challenging doses of antihistaminics were altered to parallel potency. The results are reported below.

Tripelennamine.—Doses of 100, 150, 200, and 250 mg./Kg., respectively, were administered to eight rats. Chlorpromazine (4 mg./Kg. for each 100 mg./Kg. of tripelennamine), and dextro-amphetamine (0.25 mg./Kg. for each 100 mg./Kg. tripelennamine), served as antidotes. Only at the largest challenging dosage level was it necessary to give more than one dose of dextro-amphetamine. At this level one animal died. All others recovered.

Thenylpyramine.—Dosage and antidotal procedures were identical with those for tripelennamine. However, in all cases three doses of dextro-amphetamine were given. At each of the 200 and 250 mg./Kg. levels of thenylpyramine one animal died. All others recovered.

Chlorphenamine.—Challenging doses were 10, 15,

20, and 25 mg./Kg., respectively. Antidoting doses were 4 mg./Kg. of chlorpromazine and 0.25 mg./Kg. of dextro-amphetamine for each 10 mg./Kg. of chlorphenamine. A single administration of dextro-amphetamine sufficed in all cases and all animals recovered.

At the present time, these studies are continuing. Because current antidotal procedures against antihistaminic acute toxicity leave much to be desired, any improvement in method warrants further study. It is hoped that the combination of drugs herein described, or closely related drugs to be tested in our laboratory, will continue to show promise.

REFERENCES

- (1) Krantz, J. C., Jr., and Carr, C. J., "The Pharmacologic Principles of Medical Practice," 5th ed., The Williams and Wilkins Co., Baltimore, Md., 1961, pp. 1410, 1411.
- (2) News Bulletin, Arizona Poisoning Control Information Center, Tucson, Ariz., February 1962.
- (3) Barton, C., Thomas J. Fleming Memorial Poison Information Center, personal communication.
- (4) "The Merck Index," 7th ed., Merck and Co., Rahway, N. J., 1960, p. 379.
- (5) *Ibid.*, p. 879.
- (6) Connolly, H. A., Jr., *J. Med. Soc. N. Jersey*, 56, 264 (1959).
- (7) Cill-Cary, M., *Brit. Med. J.*, 1, 687 (1954).
- (8) Broadfoot, E. M., *Med. J. Australia*, 1, 189 (1953).
- (9) Wyngaard, F. B., and SeEVERS, M. H., *J. Am. Med. Assoc.*, 94, 227 (1951).
- (10) "Thorazine—A Summary of Clinical Use," Smith Kline and French Laboratories, Philadelphia, Pa., 1955.
- (11) Loveless, M. H., *Am. J. Med.*, 3, 296 (1947).

Solubility of Carbon Dioxide, Krypton, and Xenon in Lipids

By SHU-YUAN YEH and RICHARD E. PETERSON

The solubility of carbon dioxide, krypton, and xenon has been measured at one atmospheric pressure and at temperatures of 25, 30, 37, and 45° in olive oil, dog fat, human fats, and rat-pooled fat. The solubility of the gases studied in the oil and fats was found to decrease as the temperatures increased. Heats and entropies of solution have been calculated from linear dependencies of logarithm of the solubility with reciprocal absolute temperature. There seems to be a linear relationship between solubility, surface tension, and viscosity of the lipids.

THE PRIMARY objective of this study is to obtain some precise data on the solubility of krypton and xenon in lipids for calculation of body fat in a living body. Carbon dioxide was also included in this study because of the paucity of such data in lipids.

The solubilities of carbon dioxide, air, oxygen, nitrogen, and hydrogen in corn oil, in both unhydrogenated and hydrogenated lard, and in cottonseed oil have been measured at various temperatures by several investigators (1-3). They found that all the gases, with the exception of carbon dioxide, are increasingly soluble in the

fat as the temperature rises. The solubility of carbon dioxide in human fat, dog fat, and rat fat at 38° was reported by Nichols (4). The solubility of xenon in olive oil and other aromatic oils, and of radioactive krypton and xenon in olive oil has been measured at 20, 22, and 37° by Steinberg and Manowitz (5), and Lawrence, *et al.* (6), respectively. Steinberg and Manowitz claimed their data, which are identical with Lawrence, *et al.*'s, to be accurate within 10%. It is obvious that these data are not sufficiently precise for calculating body fat in a living body.

EXPERIMENTAL

Materials Employed.—Research grade carbon dioxide, krypton, and xenon were purchased from Matheson Co. According to their specifications,

Received March 29, 1962, from the State University of Iowa, College of Medicine and Radioisotope Service, Veterans Administration Hospital, Iowa City.

Accepted for publication September 13, 1962.

This research was supported by grant No. H-4098, United States Public Health Service.

carbon dioxide contained maximum possible impurities of 0.3% mole of nitrogen, or carbon monoxide and oxygen; krypton contained maximum possible impurities of 0.04% nitrogen and xenon; and xenon contained maximum possible impurities of 0.02% nitrogen and 0.05% krypton.

Olive oil U.S.P. was purchased from Magnus, Mabee and Raynard Co., Inc.

Dog Fat.—Dog perineal, mesenteric, omental, and other adipose fats were extracted with petroleum ether C.P. (b.p. 36–65°). The fat was stored in a screw-capped jar under refrigeration after the ether was evaporated from the fat under vacuum at about 80° for several hours.

Human Fat.—Human omental fats, obtained from two different deceased patients, were marked as human fat No. 1 and No. 2, respectively, and treated as described under "Dog Fat." The human fats No. 1 and No. 2 seemed no different, except that the human fat No. 2 appeared to have more precipitate (stearine) than No. 1 at the temperature of about 23°.

Rat Fat.—Rat retroperitoneal, mesenteric, omental fats, and hair clipped skin, which was cut in about one square inch sections, were dried at about 80° under vacuum, crushed coarsely, and finally extracted with petroleum ether in a Soxhlet extractor. The procedure, as described under "Dog Fat," was then followed.

Measurement of the Solubility of Gases in Lipids.

—The apparatus used is shown in Fig. 1. *A* is a modified Geffken's gas buret (7). Burets *B* and *C* include three 20-ml. bulbs and four 5-ml. bulbs, respectively. The volume of *D* is 5 ml. and is graduated to 0.01 ml. within a 45 cm. length. The volume of the ungraduated part of the modified buret, up to stopcock 3 and the volume of the graduated parts between the marks, were calibrated with mercury at 25° and 30°. The capacity of the connecting tube, from stopcocks 3 to 7, and above the oil surface of the differential oil manometer, was determined by measuring the gas volume to fill the evacuated tube. The whole buret was enclosed in a water jacket and kept constant in temperature within $\pm 0.05^\circ$ by circulating water from a thermostat bath, which was equipped with a heating and refrigerating unit.

L is an absorption flask, of about 50 ml. capacity, with a standard taper male joint and a mercury sealing cup on the top. The volume of the absorption flask, containing the glass sealed stirring bar, *K*, up to stopcock 6, was determined by measuring the gas volume to fill the evacuated flask at several experimental temperatures.

R is a differential oil manometer, which was charged with Octoil-S (2-ethyl-hexyl-sebacate) pump oil (saturated with the experimental gas), and was kept with the pure experimental gas above the oil surfaces through stopcocks 4 and 5 after it was charged.

The connection between the pressure reducing valve, gas tank, and copper tube was screw-tightened and sealed with wax. All joints and stopcocks in the whole system were tested from point to point to make sure there was no leakage before an experiment was conducted. The pressure from any part could be evacuated down to 50–100 μ , as measured with the McLeod gauge.

Manipulation.—Part of the prepared fat was

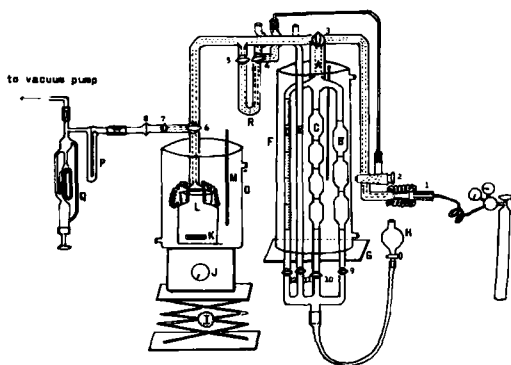


Fig. 1.—Apparatus for the determination of solubility of gases.

dried under stirring and vacuum at about 80° for about 12 hours (overnight) before it was charged to the absorption flask. All moisture or volatile materials should be evacuated under this treatment (8). The dried sample was charged to the cleaned and dried absorption flask and stirring bar by semimicro differential weighing. After the flask was assembled to the apparatus, the mercury in the gas buret was raised up to stopcock 3 and the air of the connecting system was evacuated. The gas was passed from the tank into the connecting tube and the gas buret and equilibrated with the temperature at least one hour before it was passed into the bath, *O*, and the oil was stirred and evacuated from the flask until no bubbles appeared. The apparatus was then disconnected from the vacuum pump. The gas pressure in the gas buret was adjusted to the ambient pressure and the initial reading was taken. Stopcocks 4 and 5 were turned off immediately after the reading was taken. Gas was passed into the absorption flask by turning stopcock 6 on and off occasionally until equilibrium was reached as indicated by the differential oil manometer for at least one-half hour. The temperature of the absorption flask was lowered as the thermoregulator was reset at a lower temperature. A series of solubilities at lower temperatures was obtained by this stepwise method.

This apparatus and technique have been tested with carbon dioxide in water. The solubility of carbon dioxide in water at 25, 30, 37, and 45° gave $\alpha = 0.7438, 0.7457; 0.6589, 0.6551; 0.5568, 0.5542; 0.4716, 0.4683$, compared with the literature value (30) of 0.759, 0.665, 0.562, 0.479. The reproducibility of the data, obtained from this apparatus and technique, is within $\pm 0.5\%$. It is believed that the apparatus and method described afford several advantages over other apparatus previously used. The liquid was constantly stirred in the absorption flask with a glass sealed magnet stirring rod, thus facilitating degassing as well as the saturation process and avoiding supersaturation. A considerable series of solubility data can be obtained with a single sample charged in the absorption flask. The solvent does not come in contact with mercury surfaces, thus eliminating contamination, or reaction, of the liquid with mercury. A water bath, whose temperature is easily controlled at a constant value, was used and the need for an elaborate air

thermostat was eliminated. The gas buret can be recharged for larger solubilities. It is easy to clean and dry the absorption flask and to charge the sample accurately, especially with the more viscous oil, fat, and tissue homogenates. In addition, an oil differential manometer was added to the system, thus increasing the sensitivity of the change of gas pressure within the gas buret and allowing one to easily determine whether the liquid was equilibrated with the gas or not.

The absorption coefficient, α , as defined by Bunsen (9), is given by the formula

$$\alpha = \frac{V_{o(a)} P_o}{v P} = \frac{V_{o(c_1)} + V_{o(c_2)} - V_{o(a)} - V_{o(c_2)} - V_{o(a)}}{v} \frac{P_o}{(P_B - P_S)}$$

where $V_{o(a)}$, $V_{o(c_1)}$, $V_{o(c_2)}$, $V_{o(c_2)}$, $V_{o(c_2)}$, and $V_{o(a)}$ are

the volumes of the gas absorbed, originally introduced in the gas buret and connecting tube, remaining in the gas buret, the connecting tube, and over the liquid surface in the absorption flask after equilibrium at standard temperature and pressure.

v is the volume of liquid at the saturation temperature, equal to the weight of liquid charged, divided by the density of the liquid at the saturation temperature. P is the partial pressure of the gas in mm. Hg. P_B is the corrected barometric pressure at the end of saturation. P_S is the vapor pressure of liquid at the experimental temperature and P_o is 760 mm. Hg.

Measurement of the Density of Lipids.—The densities of olive oil and fats were determined at 25 and 30° according to the standard procedure (10). The densities of olive oil and fats at the other temperatures studied were calculated according to the well established equation (11)

$$D_2 = D_1 - K(t_2 - t_1)$$

TABLE I.—SOLUBILITIES OF CARBON DIOXIDE IN LIPIDS

Lipid	Temp., °C.	Bunsen's Absorption Coefficient		Lit. Value	Ostwald Solubility Coefficient
		Mean	S.D.		
Olive oil	45	1.0150	0.0015		1.1821
	37	1.1306	0.0016		1.2849
	30	1.2519	0.0016		1.3893
	25	1.3565	0.0013		1.4806
Dog fat	45	1.0122	0.0011		1.1790
	37	1.1283	0.0014	0.861 ^a	1.2822
	30	1.2491	0.0015		1.3862
	25	1.3411	0.0022		1.4638
Human fat 1	45	1.0153	0.0020		1.1826
	37	1.1349	0.0018	0.848 ^a	1.2897
	30	1.2471	0.0015		1.3840
	25	1.3589	0.0015		1.4833
Human fat 2	45	1.0122	0.0009		1.1790
	37	1.1254	0.0014		1.2789
	30	1.2448	0.0044		1.3815
	25	1.3376	0.0044		1.4600
Rat-pooled fat	45	0.9989	0.0041		1.1635
	37	1.1125	0.0035	0.898 ^a	1.2643
	30	1.2344	0.0051		1.3700
	25	1.3363	0.0073		1.4586

^a See reference 4.

TABLE II.—SOLUBILITIES OF KRYPTON IN LIPIDS

Lipid	Temp., °C.	Bunsen's Absorption Coefficient		Lit. Value ^a	Ostwald Solubility Coefficient
		Mean	S.D.		
Olive oil	45	0.3844	0.0021		0.4477
	37	0.4031	0.0025	0.43 ^b	0.4581
	30	0.4225	0.0025		0.4688
	25	0.4376	0.0010		0.4746
Dog fat	45	0.3853	0.0004	0.44 (22°) ^b	0.4426
	37	0.4031	0.0007		0.4581
	30	0.4225	0.0013		0.4721
	25	0.4364	0.0006		0.4764
Human fat 1	45	0.3878	0.0015		0.4516
	37	0.4071	0.0005		0.4626
	30	0.4258	0.0012		0.4725
	25	0.4412	0.0061		0.4816
Human fat 2	45	0.3875	0.0012		0.4513
	37	0.4062	0.0004		0.4617
	30	0.4247	0.0013		0.4713
	25	0.4404	0.0015		0.4807
Rat-pooled fat	45	0.3847	0.0001		0.4481
	37	0.4037	0.0013		0.4588
	30	0.4219	0.0011		0.4755
	25	0.4363	0.0060		0.4762

^a Parenthesis refers to temperature which differs from present study. ^b See reference 6.

TABLE III.—SOLUBILITIES OF XENON IN LIPIDS

Lipid	Temp., °C.	Bunsen's Absorption Coefficient		Lit. Value ^a	Ostwald Solubility Coefficient
		Mean	S. D.		
Olive oil	45	1.4839	0.0012		1.7248
	37	1.6307	0.0014	1.7 ^b	1.8532
	30	1.7857	0.0013		1.9749
	25	1.8988	0.0014	1.9 (22°) ^b 1.8 (20°) ^c	2.0725
Dog fat	45	1.4589	0.0015		1.6962
	37	1.6113	0.0021		1.8299
	30	1.7557	0.0020		1.9493
	25	1.8393	0.0025		2.0084
Human fat 1	45	1.4753	0.0015		1.6904
	37	1.6143	0.0022		1.8345
	30	1.7688	0.0025		1.9630
	25	1.8878	0.0032		2.0606
Human fat 2	45	1.4742	0.0028		1.7171
	37	1.6251	0.0025		1.8503
	30	1.7645	0.0025		1.9583
	25	1.8476	0.0026		2.0166
Rat-pooled fat	45	1.4276	0.0045		1.6627
	37	1.5712	0.0050		1.7856
	30	1.7197	0.0055		1.9086
	25	1.8376	0.0065		2.0057

^a Parentheses refer to temperatures which differ from present study. ^b See reference 6. ^c See reference 5.

where D_2 and D_1 are densities of oil or fats at temperatures t_2 and t_1 , respectively. K is equal to 0.00066, a universal constant for all the oil and fats, except the rat-pooled fat, where K , equal to 0.0007 was used to fit the data obtained at 25 and 30°.

Measurement of the Viscosity and Surface Tension of Lipids.—The viscosities of olive oil and fats were determined using a Hoespler precision viscometer. The surface tensions of the oil and fats were measured with a Cenco du Nouy Surface and Interfacial Tensiometer, model 70545, using a platinum-iridium ring of 5.996 cm. mean circumference. The ratio of the radius of the ring to that of the wire of the ring (R/r) is 53.9. Measurements were made in 100-ml. beakers, having an inside diameter of approximately 5 cm. All experimental values obtained were corrected by applying the Zuidema and Waters correction equation (12). The surface tensions of the oil and fats were also measured with a Traube stalagmometer and calculated using the surface tension of benzene and toluene at 20 and 30° as reference. Five to eight determinations of the viscosity and surface tension were made for each sample. The temperature was maintained by circulation of water from a thermostat water bath.

RESULTS AND DISCUSSION

The solubility of carbon dioxide, krypton, and xenon in olive oil, dog fat, rat-pooled fat, human fats No. 1 and No. 2 was measured at temperatures of 25, 30, 37, and 45°. Each sample was measured three times. The error of those measurements will be predominantly due to the barometric pressure reading, which is assumed to have ± 0.5 mm. error and the temperature setup, which is assumed to have $\pm 0.05^\circ$ flexibility. Therefore, for the large solubility of xenon in lipids, it will cause an approximate 0.2% deviation, and for the smaller solubility of carbon dioxide and krypton, it will cause an approximate 0.15 and 0.1% deviation, respectively.

The results obtained from these measurements,

in terms of Bunsen's absorption coefficient, α , and of Ostwald's solubility coefficient, L , are presented in Tables I, II, and III. The relationship between L and α is $L = \alpha T/T_0$. The literature values taken were reduced in terms of Bunsen's absorption coefficient for uniform comparison. The data obtained from the present study agree well with the data of Lawrence, *et al.* (6), who measured the solubility of radioactive krypton and xenon in olive oil at 22 and 37°.

It is very interesting to note that although the fatty acid compositions of the oil and fats differ, the respective solubilities of carbon dioxide, krypton, and xenon are essentially the same in the oil as in the fats. Using olive oil as a standard, the deviation of the solubility ratio of the fat to olive oil is $\pm 0.15\%$. These findings agree with the data of Nussbaum (13), who reported that the solubilities of the highly fat-soluble inert gas, radon, in fatty acid and synthetic triglycerides, increases with an increase in the number of carbon atoms per mole of fatty acid. This holds up to 7 carbon atoms per molecule. There then "appears to be a slight, and possibly insignificant, decline in solubility as the number of carbon atoms per molecule increase above eight."

Effect of Temperature on Solubility.—For an isothermal process, the effect of temperature on solubility of gas in liquid can be obtained as follows (14)

$$\log L = \frac{-\Delta H^\circ}{2.303RT} + \frac{\Delta S^\circ}{2.303R}$$

Graphically, $\log L$ is a linear function of $1/T$. Heat of solution, ΔH° , and entropy of solution, ΔS° , can be calculated from the slope and intercept of the straight line. The solubility of carbon dioxide, krypton, and xenon in the oil and fats in present studies was found to decrease as temperature increased. In this respect, our data agree with the data of Clever, *et al.* (15), covering the solubility of krypton and xenon in nonpolar hydrocarbon solvents and perfluoromethylcyclohexane. Interestingly, Clever, *et al.* (15a), and Lanning (16) reported

that the solubility values of helium, neon, and argon in both nonpolar hydrocarbon solvents and polar organic solvents increased as the temperature rose. In plotting logarithms of the solubility of carbon dioxide, krypton, and xenon in the oil and fats against the reciprocal absolute temperature, straight lines were obtained. The heats and entropies of solution, calculated according to the least square method, are essentially the same in the oil as in the fats. The heat and entropy of solution for krypton is -1185 ± 46 cal./mole, -5.6 ± 0.10 cal./mole; for carbon dioxide -2713 ± 30 cal./mole, -8.5 ± 0.10 cal./mole; and for xenon -2273 ± 80 cal./mole, -6.4 ± 0.2 cal./mole, respectively.

Solubilities and Surface Tension of Solvent.—Assuming the energy change on transferring a gas molecule from the gas phase to the solution is the sum of two energy changes: (a) the energy expended to create a cavity of gas molecule radius, γ , in the solvent and (b), an interaction energy that arises when the gas molecule is placed in the cavity; Uhlig (17) derived the following equation

$$1nL = 4\pi r^2\sigma/kT + E/kT$$

which predicts that a linear relation should be formed between the logarithm of the Ostwald coefficient, L , and the solvent's surface tension, σ , assuming the interaction energy, E , is a constant for the various solvents, and K is Boltzmann's constant. Both Uhlig and Clever, *et al.* (15), found this relationship to be justified. However, Gjaldbaek (18) found this relationship does not hold for water to which surfactant has been added. Our data indicate that gas solubility increases with increasing surface tension of lipids. Plotting logarithm of Bunsen's absorption coefficient against the surface tension of the oil and fats at different temperatures, straight lines were obtained. This result is in contrast to the inverse relationship between surface tension and gas solubility in a variety of hydrocarbon solvents at one temperature deduced by Uhlig (17).

Solubility and Viscosity of Solvent.—Winkler (19) proposed an equation relating solubility to viscosity. The equation is

$$\frac{\alpha_1 - \alpha_2}{\alpha_1} = \frac{Z_1 - Z_2}{Z_1} \frac{\sqrt[3]{M_g}}{K}$$

in which Z_1 and Z_2 are the viscosities at temperatures t_1 and t_2 . M_g is the molecular weight of the gas. For five diatomic gases in water, K was found to be nearly equal to the cube root of 54, three times the molecular weight of water. Steinberg and Manowitz (5) reported that the less viscous silicone oil (1 centistoke) had a 63% higher xenon solubility than the more viscous silicone oil (10 centistoke). Using our data and applying the Winkler equation, the calculated (average of 30 data) K values are 8.13, 21.7, and 13.8 for carbon dioxide, krypton, and xenon, respectively. Our data suggest that gas solubility decreases with a decrease in the viscosity of the lipids. Plotting logarithm of Bunsen's absorption coefficient against logarithm of viscosity of the oil and fats at different temperatures, straight lines were obtained. Our data are in agreement with the statement of Thorpe and Rodger (20). They stated that, "Winkler's conclusion must be changed to: for same gas, the decrease in solubility (not percentage decrease) is proportional to the corresponding decrease in viscosity, and further, for any gas, the factor of proportionality is greater for a greater molecular weight, but no simple relation exists."

The linear relationship obtained from a plot of the logarithm of the solubility, against the surface tension, or logarithm of the viscosity of the lipid, appears to be a cross-relation plot. These relations can also be considered as a relation between solubility and temperature, since the surface tension and viscosity change as temperature varies.

Past efforts to elucidate the forces and factors which determine solubility have provided information on surface tension (17), viscosity (5,19), and the empty volume (15b) of the solvent as being related to gas solubility. Since our studies involved lipid mixtures, it was impossible to calculate Bondi's empty volume (15b). Our data of surface tension and viscosity measurements of solvents as well as those reported in the literature (15,17) were ob-

TABLE IV.—SURFACE TENSION AND VISCOSITY

Lipid	Temp. °C.	Surface Tension, Dynes/cm.						Lit. Values ^a	Viscosity, Centipoises		
		Uncorrected Mean	S.D.	Corrected Mean	S.D.	Drop weight Mean	S.D.		Mean	S.D.	Lit. Values ^a
Olive oil	45	33.55	0.07	30.05	0.06	30.10	0.04	33.8 (50°) ^b	29.91	0.14	24 (50°) ^c
	37	34.10	0.08	30.56	0.07	30.76	0.11	33.6 ^c ; 34 (40°) ^b	39.08	0.10	46.68 ^f
	30	34.65	0.05	31.07	0.04	31.03	0.10	34.9 ^b ; 33.9 (32°) ^c	51.05	0.26	41 (33.5°) ^c
	25	35.02	0.04	31.41	0.03	31.47	0.25	34.2 (27°) ^c	61.90	0.13	77 (20°) ^e
Dog fat	45	25.22	0.10	22.20	0.09	22.35	0.17	34.2—35.4(20°) ^d	33.73	0.13	
	37	25.65	0.07	22.70	0.06	22.66	0.27		44.58	0.22	
	30	26.22	0.09	23.25	0.08	23.50	0.18		57.84	0.10	
	25	26.60	0.10	23.56	0.09	26.96	0.24		71.28	0.10	
Human fat 1	45	24.30	0.10	21.46	0.09	21.30	0.24		32.95	0.10	
	37	25.05	0.10	22.10	0.09	21.72	0.21		42.31	0.09	
	30	25.54	0.10	22.59	0.09	22.30	0.25		55.68	0.17	
	25	26.96	0.11	22.96	0.10	22.63	0.29		68.29	0.09	
Human fat 2	45	23.52	0.04	20.75	0.04	20.57	0.20		32.37	0.10	
	37	24.10	0.10	21.25	0.09	21.16	0.24		48.46	0.13	
	30	24.54	0.11	21.69	0.10	21.51	0.26		56.98	0.05	
	25	24.92	0.11	22.05	0.10		69.43	0.15	
Rat- pooled fat	45	24.71	0.10	21.98	0.09	22.24	0.08		33.94	0.07	
	37	25.85	0.14	22.85	0.13	23.43	0.16		44.77	0.09	
	30	26.70	0.06	23.66	0.05	23.80	0.28		59.21	0.08	
	25	27.32	0.04	24.22	0.03	24.31	0.10		72.81	0.05	

^a Parentheses refer to temperatures which differ from present study. ^b See reference 24. ^c See reference 26. ^d See reference 25. ^e See reference 27. ^f See reference 28.

tained with the solvents saturated with air. No data are available for measurements with degassed solvents or solvents saturated with the experimental gas.

The vapor pressures of the oil and fats, which are involved in the calculation of the solubilities, are negligible. The vapor pressures of olive oil and hydrogenated cottonseed oil have been reported as 0.001, 0.37, 0.01, and 0.04 mm. at 25°, respectively (21–23). Likewise, the natural fats have very low pressures.

The uncorrected surface tensions (maximum pull P) of the olive oil in the present study agree well with the data of Halpern (24), of Kaufmann and Kirsch (25), and of Canals, *et al.* (26). After applying the Zuidema and Waters correction (12), the surface tensions of the oil and fats of our present study were 10% lower than the data of Halpern, of Kaufmann and Kirsch, and of Canals, *et al.*, which we assumed are uncorrected. To further check this point, the drop weight method has been used to measure the surface tension of oils and fats over the same range of temperatures. For the purposes of comparison, uncorrected and corrected surface tensions of the lipids are presented in Table IV.

SUMMARY

1. The solubility of carbon dioxide, krypton, and xenon in olive oil, dog fat, rat-pooled fat, and human fats, has been measured at one

atmosphere and at temperatures of 25, 30, 37, and 45°. The solubility of these gases in the above mentioned oil and fats is essentially the same, except for the rat-pooled fat, which is slightly less.

2. The heats and entropies of solution, calculated according to the least square method, are essentially the same in the oil as in the fats.

3. The viscosity and surface tensions of the oil and fats have also been measured at the temperatures of 25, 30, 37, and 45°. The density of olive oil and fats has been measured at the temperatures of 25 and 30°.

REFERENCES

- (1) Vibrans, F. C., *Oil Soap Egypt*, **12**, 14(1935).
- (2) Schaffer, P. S., and Haller, H. S., *ibid.*, **20**, 161(1943).
- (3) Parsons, L. B., "Industrial Oil and Fat Products," Interscience Publishers, Inc., New York, N. Y., 1954, p. 100.
- (4) Nichols, G., Jr., *Science*, **126**, 1244(1957).
- (5) Steinberg, M., and Manowitz, B., *U. S. At. Energy Comm.* BNL 493(T-115), Feb. 1958.
- (6) Lawrence, J. H., Loomis, W. F., Tobias, C. A., and Turpin, F. H., *J. Physiol. London*, **105**, 197(1946).
- (7) Geffken, G., *Z. Physik Chem.*, **49**, 257(1904).
- (8) "Official Methods of Analysis of the Association of Official Agricultural Chemists," 8th ed., which cited *Ind. Eng. Chem. Anal.*, **18**, 1347(1926); *J. Assoc. Offic. Agr. Chemists*, **14**, 247(1931); *ibid.*, **15**, 560(1932).
- (9) Bunsen, R., *Phil. Mag.*, **9**, 116, 181(1855).
- (10) Reilly, J., and Rae, W. N., "Physico-chemical Methods," Vol. 1, Van Nostrand Co., Inc., New York, N. Y., 1953, p. 613.
- (11) (a) "International Critical Tables," Vol. 2, 210(1928) cited in Wright, C. H., *J. Soc. Chem. Ind.*, **26**, 513(1907); (b) Eckey, E. W., "Vegetable Fats and Oils," Reinhold Publishing Corp., New York, N. Y., 1954, p. 102.
- (12) Zuidema, H. H., and Waters, G. W., *J. Ind. Eng. Chem. Anal.*, **13**, 312(1941).
- (13) Nussbaum, E., "Radon Solubility in Body Tissues and in Fatty Acids," University of Rochester Atomic Energy Project UR-503, September 17, 1957.
- (14) Glasstone, S., "Textbook of Physical Chemistry," 2nd ed., pp. 232, 827.
- (15) (a) Clever, H. L., Bathino, R., Saylor, J. H., and Grass, P. M., *J. Phys. Chem.*, **61**, 1078(1957); (b) *ibid.*, **61**, 1082(1957); (c) Clever, H. L., Saylor, J. H., and Grass, P. M., *ibid.*, **62**, 89(1958).
- (16) Lanning, A., *J. Am. Chem. Soc.*, **52**, 68(1930).
- (17) Uhlrig, H. H., *J. Phys. Chem.*, **41**, 1215(1937).
- (18) Gjaldback, J. C., *Acta Chim. Scand.*, **7**, 537(1953).
- (19) Winkler, L. W., *Z. Physik Chem.*, **9**, 171(1892); *ibid.*, **55**, 344(1906).
- (20) Thorpe, T. E., and Rodger, J. W., *Chem. News*, **70**, 45(1894); *J. Chem. Soc.*, **65**, 782(1894).
- (21) Perry, E. S., Weber, W. H., and Daubert, B. F., *J. Am. Chem. Soc.*, **71**, 3720(1949).
- (22) Lederer, E. L., *Seifensieder Ztg.*, **57**, 67(1930).
- (23) Bailey, A. E., *Ind. Eng. Chem.*, **33**, 404(1941).
- (24) Halpern, A., *J. Phys. Colloid Chem.*, **53**, 895(1949).
- (25) Kaufmann, H. P., and Kirsch, P., *Fette u. Seifen*, **47**, 191(1940).
- (26) (a) Canals, M. E., and Ramahenia, Ranaivo, *J. Pharm. Chim.*, **16**, 431(1932); (b) *ibid.*, **17**, 505(1933); (c) *ibid.*, **18**, 438(1933); (d) Canals, M. E., and Flous, M. E., *ibid.*, **20**, 241(1934).
- (27) Kaufmann, H. P., and Funke, S., *Fette u. Seifen*, **45**, 255(1938).
- (28) Rescorla, A. R., and Carnahan, E. L., *Ind. Eng. Chem.*, **28**, 1212(1936).
- (29) Fidanza, F., Keys, A., and Anderson, J. T., *J. Appl. Physiol.*, **6**, 252(1953).
- (30) "Handbook of Chemistry and Physics," 43rd ed., Chemical Rubber Publishing Co., 1961–1962.

TABLE V.—DENSITY OF LIPIDS

Lipid	Temp., °C.	Density $t/4^\circ$	
		Mean	Lit. Value
Olive oil	45	0.9011	
	37	0.9064	
	30	0.9110	
	25	0.9143	
Dog fat	15	0.9150	0.915–0.920 ^a
	45	0.8974	
	37	0.9027	0.9155 ^b ; 0.9103 ^c
	30	0.9073	
Human fat 1	25	0.9116	0.9118 ^c
	45	0.8965	
	37	0.9017	0.9110 ^b ; 0.9000 ^c
	30	0.9064	
Human fat 2	25	0.9097	0.9090 ^c
	15	0.9163	0.9167 ^c
	45	0.8972	
	37	0.9025	
Rat-pooled fat	30	0.9072	
	25	0.9104	
	45	0.9002	
	37	0.9058	0.9154 ^b ; 0.9038 ^c
fat	30	0.9107	
	25	0.9142	0.9121 ^c

^a See reference 11a. ^b See reference 4. ^c See reference 29.