A Characteristic Property of Whale Oils concerning the Absorption of Gases

I. On the Absorption of Carbon Dioxide by Whale Oils

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A peculiar thing about whales is the fact that a special organ, *spermaceti*, is present only in sperm whales and that a large amount of wax is present both in the sperm oil and body oil. None of other animals are known to possess *spermaceti* or any organs similar to it. As for the presence of a large amount of wax, similar presence is known in a sperm porpoise but in none of the other whales, in which the oil is largely constituted of glycerides as in other mammals.

First of all, studies about oils and fats in the food of sperm whales must be referred, but studies in this direction are comparatively few. According to E. André and H. Canal,[1] the amount of unsaponified matter in the oil of a squid (*Todarus sagittatus L. K.*) is comparatively large but it does not contain higher alcohols. M. Tsujimoto and H. Kimura[2] have shown that the oil of a squid (*Omnastrephes soloani pacificus*) contains a small amount of unsaponified matter, so that the amount of higher alcohols, even if present, would probably be small. It follows, therefore, that the higher alcohols present as a component of the large amount of wax in the sperm whale do not come directly from the oil taken as food and it seems more pertinent to assume that such alcohol is synthesized in the body of sperm whales by some process. Aside from such a process, a doubt arises about the physiological significance of the presence of wax, in this animal.

On the other hand, it is known that sperm whales are able to dive much deeper and stay submerged much longer than the other whales. Would it be irrational to place some correlation between this fact and the presence of a large amount of wax? Such presumptive correspondence was an incentive for the present work.

Here we may assume a third physiological function of the oil as a gas reservoir and gas exchange matter, besides those as an energy source and heat insulating matter. It seemed of interest, then, to find out how the three kinds of gases concerned with respiration, oxygen,

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[1] E. André et H. Canal: Compt. rend., **183**, 152 (1926).

[2] M. Tsujimoto and H. Kimura: J. Chem. Ind. (Japan), **30**, 865 (1927).

nitrogen and carbon dioxide, are absorbed in sperm oil and other oils and fats.

In the present series of experiments, tests were made with the absorption of carbon dioxide in three kinds of whale oils, in comparison with a few kinds of vegetable oils, water and other experimental materials. After describing the apparatus and procedure used, some remarks on test materials will be made, and the results obtained, will be offered.

Apparatus and Procedure

The apparatus used for the present series of experiments is schematically shown in Fig. 1. The main portion consists of a pressure-vessel, **A**; gas reservior, **C**; and a manometer, **D**. Their relative position is not changed during the course of the whole experiment.

Pressure-vessel (made of steel of 5 mm. thickness; internal volume, 656 cc., plated with chromium) is to hold the liquid to be tested. This is suspended from the crank **B** of the crank shaft (1 inch in dia.). The vessel is provided with three outlet-tubes; ***a***, ***b*** and ***c***, each with a stop-cock. Tube ***a*** is tightly connected to the gas reservoir and ***b*** to the manometer, each through a thick-walled rubber tubing (internal dia., 3 mm., external dia., 22 mm.). The gas reservoir **C** is about 40 liter capacity and is also provided with three outlets each with a stop-cock, and a pressure gauge. After removal of the internal air, test gas is led into reservoir, until of desired pressure. The pressure-vessel, **A** and the gas reservoir, **C** are each immersed in water tanks, **E** and **F**, respectively. The temperature of water in tanks, was

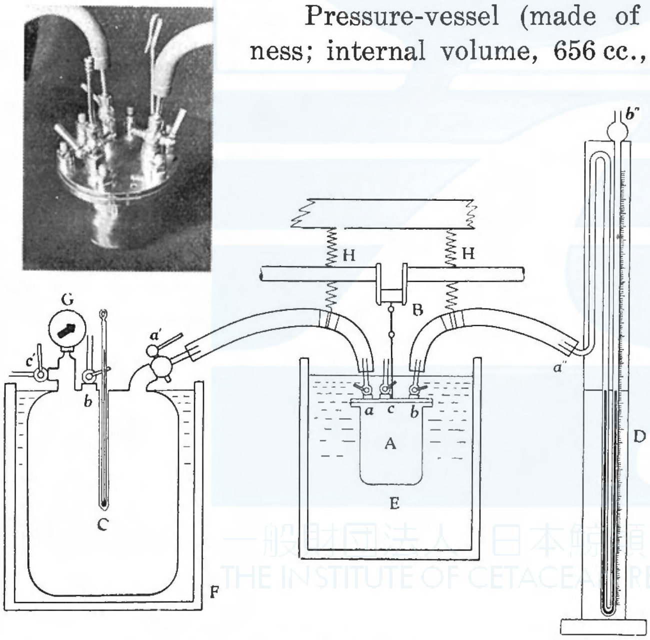

Fig. 1. Apparatus used for the Measurement of Gas Absorption.

A: Pressure-vessel. **B**: Crank.
C: Gas reservoir. **D**: Manometer.
E and **F**: Water tanks with water being kept at 35°C.
G: Pressure gauge. **H**: Spring.

ajusted at 35±0.5°C. The capacity of the each water tanks is about 70 l. The mercury manometer, **D** is of an open type, 2.2 m. in height, and graduated in 1 mm. intervals.

One of the most indipensable conditions for the carrying out of this experiment, is that the pressure-vessel, **A** and the manometer, **D** must be completely isolated from the outside air, as one pressure system. In other words, there must be no leaks in joints, cocks and in other parts. In the present series of experiments, pressure test under 3 atm. pressure, during six hours, indicated that the decrease of pressure was only about 2 to 3 mm. Hg. The stop-cocks were made of gun metal, quite closely ground, and secured with a strong spring. The other indispensable condition is the constancy of the movement of the pressure-vessel, which required some device. For exsample, rubber tubings were suspended from above with a spring so as to avoid their contact with other parts and also to avoid the effect of weight of the rubber tubing on the motion. These precautions seem to have effected constancy of the movement, at least, as far as the results of the present series of experiments are concerned.

The materials to be tested for gas absorption were taken at 100 gs. in each experiment. This sample is placed in the vessel, **A** and suctioned under 1–2 mm. Hg to effect deaeration. In non-volatile liquid, excluding water, deaeration can be carried out for as long as desired. No special experiments were made to find out how much deaeration was sufficient in each material. However, insufficient deaeration would show the effect in experimental results (in the absorption velocity and the amount of maximal absorption). In general, liquids which absorb gas rapidly, also liberate the gas rapidly. This seems perfectly clear to the author. Deaeration of a liquid in a boiling water bath, during twice the time it took until maximal absorption, was found to be sufficient to insure constancy in absorption tests. The time length of deaeration was determined according to this standard. This deaeration in a boiling water bath is followed by suction for 30–40 minutes, in the water tank **E**, maintained at 35°C.

In the case of water,. however, the foregoing deaeration cannot be carried out, because water is volatile. Destilled water thoroughly boiled, is placed in a bottle and cooled under reduced pressure. From this, 102 cc. is taken into the pressure-vessel, closed, and suctioned up to 40 mm. Hg in the water tank **E**, maintained at 35°C. When this pressure is reached, the cock *c* is closed and the vessel is allowed to stand for 1 hour in this state, during which the pressure inside the vessel rises to about twice the original by the vapor pressure of water. Finally, the vessel is evacuated to the highest degree, for exactly

1 min., and the next procedure is started. The question here, is how much water is lost by this procedure. It was found, through weighing the water in the vessel at the end of the test, that 99–99.5 gs. of water still remain in the vessel.

The apparatus is now ready with the vessel **A**, containing the material to be tested, completely deaerated and maintained under 1–2 mm.Hg, suspended from a crank **B**, and immersed in water with top of the tubes barely visible. Other cocks are all closed but only *a* and *b* are open. Then the cock *a'* is gradually opened to send the gas from the gas reservoir into the pressure-vessel until the mercury in the manometer reaches the desired height. Cock *a'* is then closed, followed immediately by the closing of cock *a*, by which the pressure-vessel, **A** and the manometer, **D** constitute one isolated system. This instant, another operater reads the manometer at the time 0, switches on the motor, and starts the stop watch, and the manometer is read punctually with passage of time. The crank shaft is revolved at 77–78 r.p.m., at a voltage of 100–110 V.

The uncertainness about this experimental procedure are the impossibility of taking an accurate reading at the time 0 and the possibility of gas absorption, starting at the time of the introduction of the gas into the vessel, even before the periodical motion of the vessel begins. It is not clear about the second point, but it has been observed that the fall of pressure is extremely gradually in a static state, and that a marked fall occurs as soon as the movement started. It may be added that a period of 20–30 sec. elapsed for the introduction of gas, until of desired pressure. As for the first point, it is actually difficult to take an accurate reading, since there is present a vertical oscillation of the mercury and the surface tends to fall with time. But the readings after 10 sec. and later can be made with accuracy by practice. The determination of the pressure value at the outset was made on the following assumption: As will described later, it is proved that, if we plot logarithms of the pressure value which decreasing with time, against logarithms of time, the curve obtained, in all of the cases become linear. Based on the assumption, the value of pressure at the time 0, can be computed. The value so obtained was found to agree approximately with the observed value, when the absorption velocity was small. But the discrepancy between them showed 6 mm. Hg, at the maximum, when the velocity was greater.

The foregoing measurements were made with each of the materials under various pressure-lebels. Five lebels were chosen for each material, that is, near (but a little higher) 1, 2 and 3 atm. pressure in their initial pressure values, and two intermediate lebels between those.

We attempt to set the initial pressure P_i as near as possible, between the corresponding lebels of each material, values of P_i and P_f (final pressure) are listed in cols. 2 and 3 respectively, of Tab. 2. In the present report, we always use the absolute pressure, i.e. the differential pressure of the manometer added with the atm. pressure at the time, in mm. or cm.Hg. In some materials, tests were made under three P_i lebels, omitting the two intermediate lebels,

As described above, in the present series of experiments, the decrease of pressure was measured under constant volume.

If we write P_i and $P_i-\Delta P$, for the pressure value at the time 0 and t respectively, and V (which is constant) for the real volume of the vessel, the gas at the time t, will be in a state of $P_i-\Delta P$, V., then the following equation hold for the same state of the equal amount of gas, at the time t

$$(P_i-\Delta P)V=P_i\ (V-\Delta V)$$

or

$$\Delta V=\frac{V}{P_i}\Delta P\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where ΔV stands for the decrease in volume, when the absorption is assumed to occur under constant pressure P_i. Furthermore we have

$$\Delta V_0=\frac{T_0}{T}\frac{1}{P_0}V\cdot\Delta P\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where ΔV_0 represents the decrease in volume under standard condition. This decrease is to be considered as the volume of gas absorbed by the materials during the time t. $\frac{T_0}{T}\frac{1}{P_0}$ is a common constant disregarding the materials. V becomes also constant with respect to the material chosen, that is,

$$V=V_1-V_2$$

V_1 denotes the whole capacity of the vessel, which is found to be 684±3 cc., including the inner space of rubber- and glass tubings. 684 cc. is taken as the basis of the computation. $V_2=100/d$, where d is the specific gravity of the liquids tested.

Therefore ΔV_0 can be obtained by multiplying ΔP with these constant factors.

Experimental Materials

The main purpose of the present study is the examination of carbon dioxide absorption by whale oils. Three kinds of whale oil*; sperm oil,

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* Kindly supplied by the Taiyo Fisheries Co., Ltd.

body oil of sperm whale and whale oil from fin whale, were chosen as the material. The first two are from sperm whale, and contain a large amount of higher alcohol esters. The other is from fin and blue whales, or it may contain the oil from sei whale. This point is unknown to the author but at least the oil comes from baleen whales and the majority of it, is constituted from glycerides, as is clear from table 1. Distilled water was chosen as the material. Water is the most common and the most important physiological substance and it seemed suitable to study it in comparison with oils. In this sense, approximately 1% saline solution was also added.

Table 1. Physical and Chemical Natures of the Materials

Materials	Specific Gravity D_4^{35}	Index of Refraction	Viscosity (35°) Redwood (sec.)	Acid Value	Saponification Value	Iodine Value	Unsaponified Matter %
Dist. Water	0.994	—	9.2	—	—	—	—
ca. 1% Saline Solution	1.005	—	—	—	—	—	—
Sperm Oil	0.860	n_D^{40} 1.4525	27.8	1.36	145.5	56.56	33.66
Sperm Body Oil	0.875	n_D^{40} 1.4586	32.8	2.18	141.0	72.64	31.74
Whale Oil	0.917	n_D^{20} 1.4728	47.3	1.95	197.4	99.10	0.46
Olive Oil	0.907	n_D^{18} 1.4695	64.2	2.12	192.0	87.23	0.58
Camellia Oil (commercial)	0.903	n_D^{15} 1.4692	57.8	2.13	192.1	79.37	0.80
Camellia Oil (extracted)	0.904	n_D^{15} 1.4677	55.9	1.85	190.5	81.23	0.93
Castor Oil	0.965	n_D^{15} 1.4790	410.7	2.01	190.1	86.84	0.48
Oleic Acid	0.891	n_D^{18} 1.4588	28.9	—	—	89.09	—
Oleyl Alcohol	0.811	n_D^{15} 1.4602	33.5	—	—	93.50	92.8
Liquid Paraffin	0.874	—	96.5	—	—	—	—

Several kinds of vegetable oil were tested in comparison with whale oil, because they are contrasting in their presence and were assumed to be rather contrasting in their functions. Olive oil was chosen as a common vegetable oil, camellia oil as that with low viscosity and castor oil as that with extremely high viscosity. Special attention was paid to the viscosity because, higher the viscosity, the smaller would be the internal motion against mechanical force and this might become a factor to decrease the absorption velocity. On the other hand, there is also a possibility that an oil with high viscosity might have ability to absorb larger amount of gas. Two kinds of camellia oil were tested because the commercial camellia oil had been unexpectedly found to have a very small absorption velocity, in spite of a low viscosity. Because of the doubt about its purity, oil was extracted from the seeds of *Camellia japonica L.* in this Laboratory.

Further, oleic acid and oleyl alcohol were chosen, as these were the components of oils and fats. Glycerin, the other component of the oil, was omitted because its absorption velocity was extremely small, far smaller than that of castor oil. From only one experiment, its saturation value was supposed to be about that of water. Liquid paraffin was chosen as one of the materials, because this was expected as a matter of poor absorption. Physical and chemical properties of the materials used in the present study are listed in table 1.

Results

Maximal Amount of Carbon Dioxide, absorbed by 100 gs. of Various Materials :

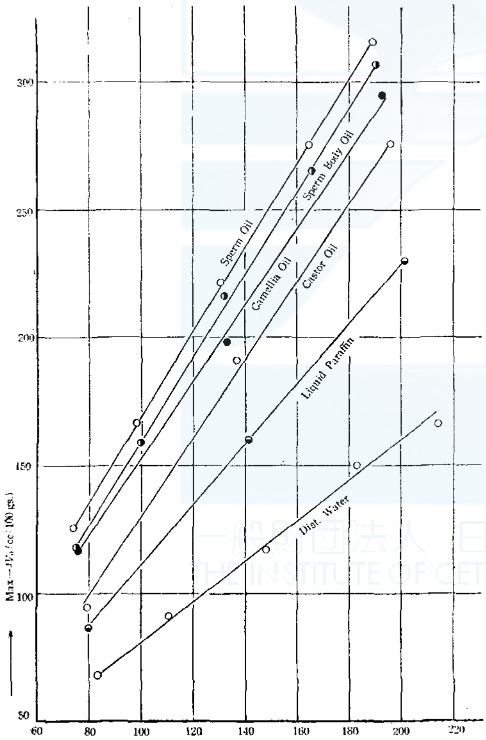

Fig. 2a. Relationship between Maximal Volume of CO_2 (cc/100 gs.) and Final Pressure (cm.Hg), in Various Materials.

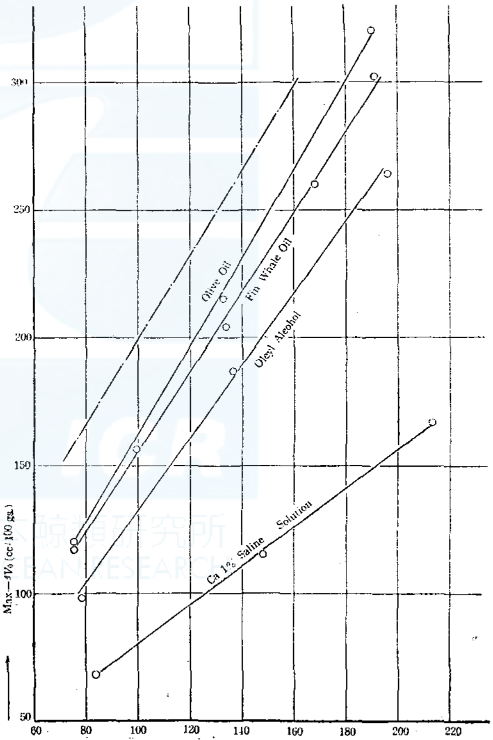

Fig. 2b. Relationship between Maximal Volume of CO_2 (cc/100 gs.) and Final Pressure (cm.Hg), in Various Materials. (Broken line drawn parallel to the line for sperm oil).

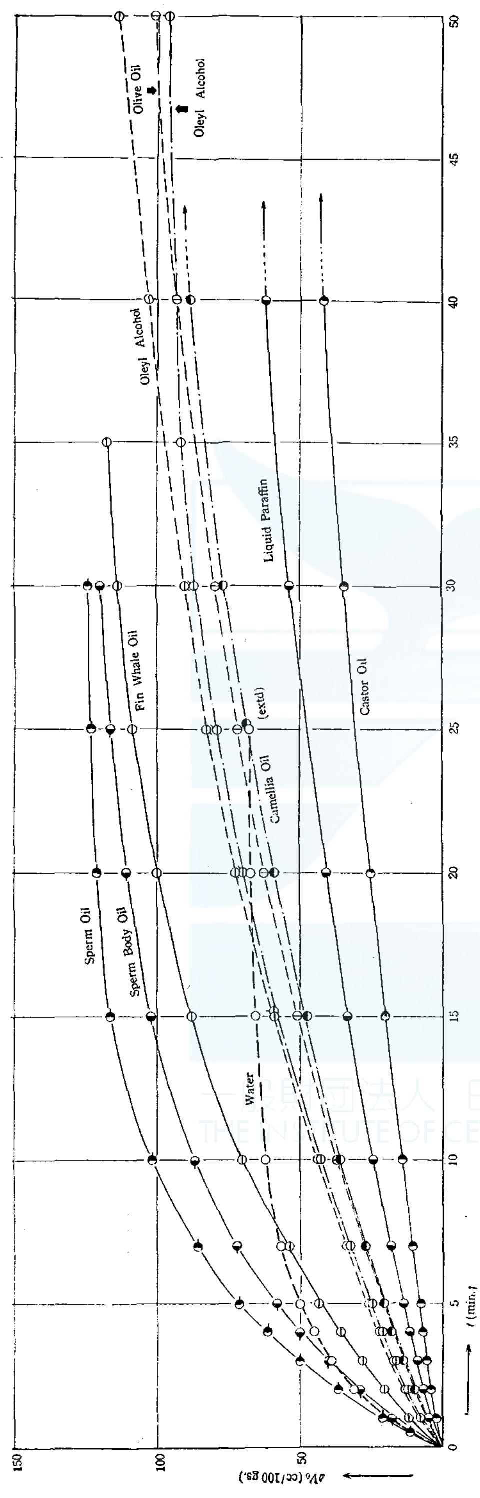

Fig. 3. Absorption Curves for Each Material under around 1 Atm. Pressure (P_i=927–936 mm. Hg).

A few preliminary tests suggested that there would be no great difference in the solubility of CO_2 in oils and fats and other materials tested in the present series of experiments, with the exception of water. Therefore heavy attention was not paid to this point, and no measurements were carried out for so long as required until a true saturation was reached. Nevertheless, the measurements were made until the velocity $\frac{d}{dt}(\Delta V_0)$ becomes fairly small in all the cases. The duration of the time elapsed in each measurement differed to a great extent with each material, as shown in col. 4 of tab. 2. Even if the maximal value of ΔV_0 in these experiments does not represent the saturated value, it may be taken as a value comparatively near it.

Figs. 2a and 2b give the graphs with max-ΔV_0 (in cc./100 gs. of material) plotted against the P_f (in cm. Hg). fig. 2 has been separated into two portions but there is no special significance in that, except that in some materials, their curves fall so near to each other that they can not be represented on one graph. Even by such treatment, curves for oleic acid and the comm. camellia oil had to be

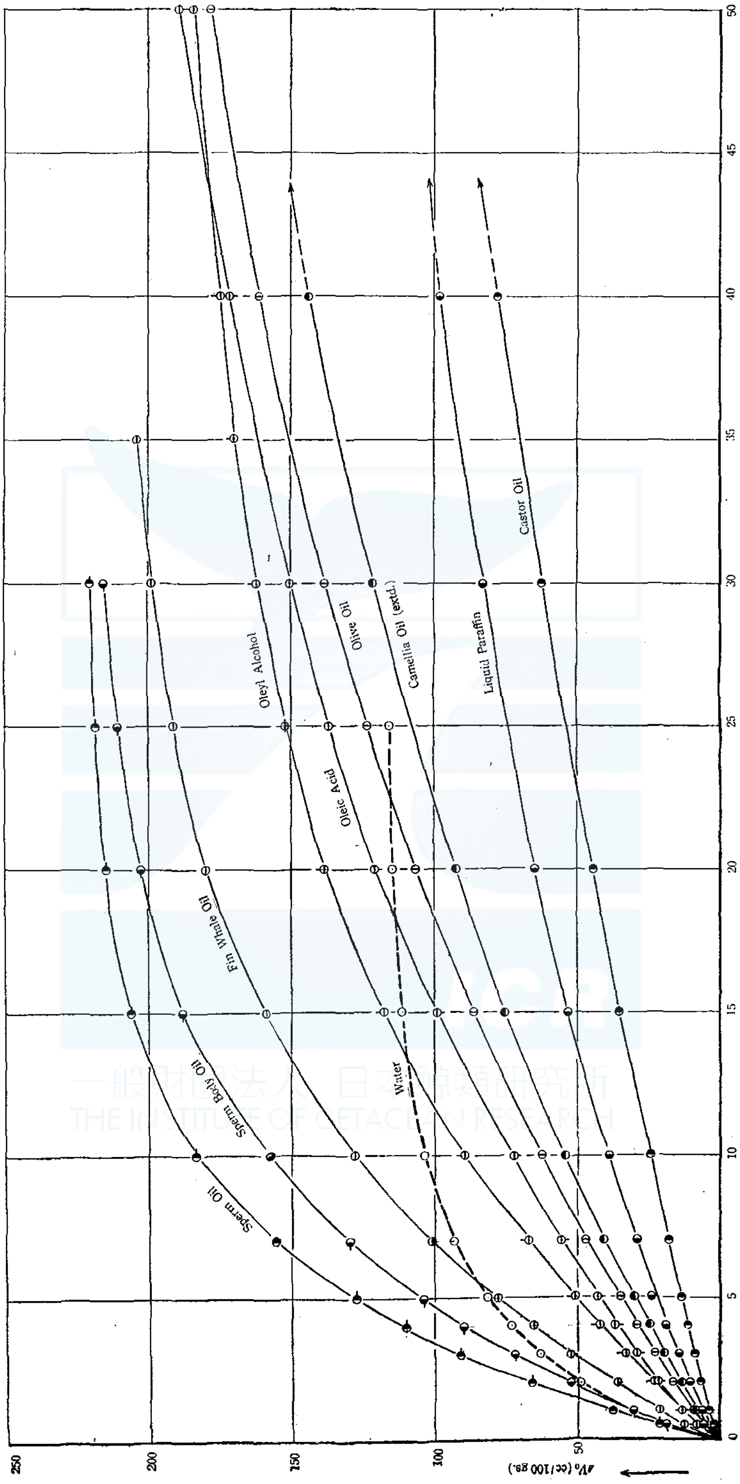

Fig. 4. Absorption Curves for Each Material under around 2 Atm. Pressure (P_i=1640-1656 mm.Hg).

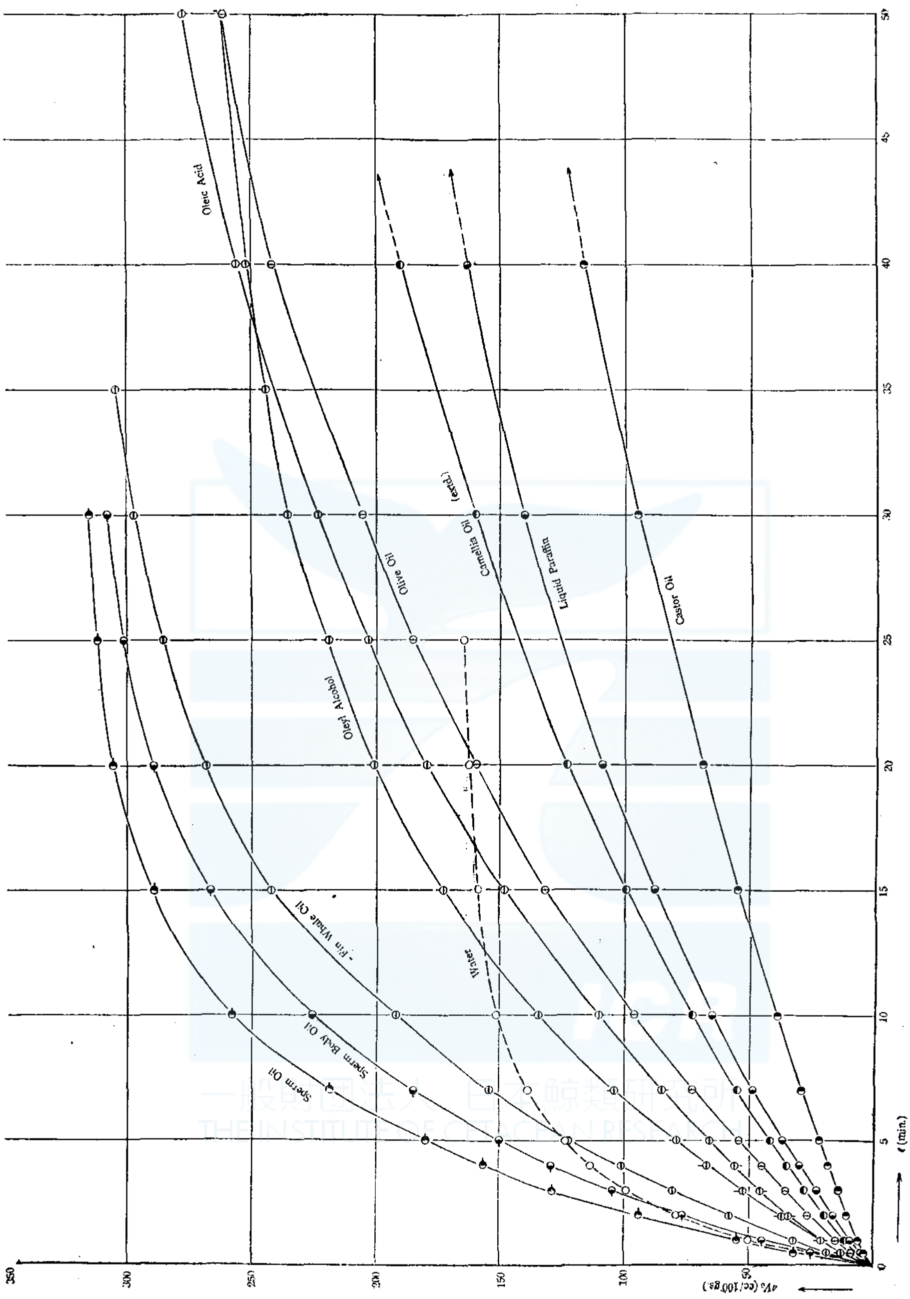

Fig. 5. Absorption Curves for Each Material under around 3 Atm. Pressure (P_i=2361–2382 mm.Hg).

discarded. It may be seen from figs. 2a and 2b that the value of Max-ΔV_0 had a tendency to show a linear regression against P_f. The gradient of the straight line is 1.78 cc./cm.Hg in sperm oil, and values approximating it, with sperm body oil, olive oil, oleic acid, camellia oil and fin whale oil. Even in castor oil, whose absolute value of Max-ΔV_0

is small, there seemed to be no great difference in the gradient of the line. On the other hand the gradient of the curve in water is 0.78 cc./cm. Hg, being 1/2 or less of that of the materials listed above. The curve of ca. 1% saline water completely overlapped that of the dist. water.

If the equation ; Max-ΔV_0=c. P_f can be postulated, then it means that Max-ΔV_0 (and perhaps solubility also) is proportional to the pressure, in each material, and solubilty of CO_2 in water would be about one-half of that of the foregoing oily substances, irrespective of the pressure. In any case, it is clear, that the solubility of carbon dioxide in oily substances is not so markedly different with the kind of oils and fats, as long as the duration of time required until saturation, is not taken into account. On the other hand, the time required to reach the saturation differs vastly with different kind of oils.

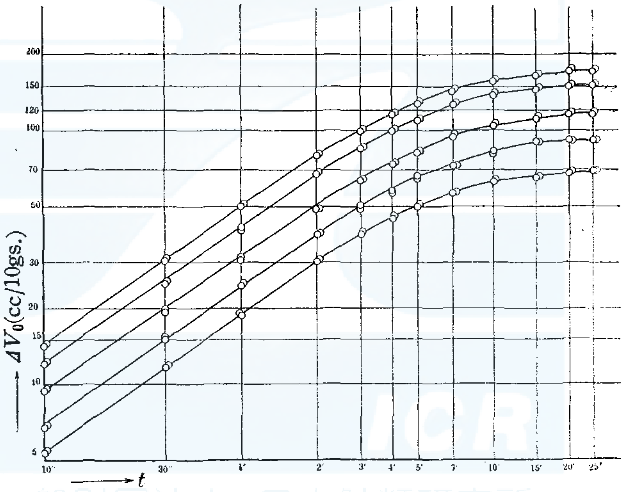

Fig. 6. Absorption Curves for Dist. Water under various Pressure lebels. ΔV_0: Volume of CO_2 (cc/100 gs.) absorbed. t : time (sec.). Pressure lebels (mm.Hg) from top to bottom: 2382–2139, 2061–1841, 1656–1483, 1240–1106, 934–838.

Absorption Curve of Carbon Dioxide, by 100 gs. of Various Materials :

It is seen from the preceding section, that the rapidity of absorption differs with each material. The main purpose of the present section is to follow the absorption curve of carbon dioxide in several oils, including whale oils and other liquid materials, and to find from it, the characteristic difference between them as to such properties as how rapid they can absorb gases. The values of ΔV_0 (in cc.) obtained were all transformed into logarithms and these plotted against the logarithm of t's (in sec.), because to find out the experimental formula. But it may be necessary to show the raw curves. In the transformed curves, it seems that all materials give almost similar results, as long as the special attention was not paid to the ordinate scale.

Fig. 3 shows the absorption curves of various materials under around 1 atm. pressure, and figs. 4 and 5 respectively give those under around 2 and 3 atm. pressure. In each figure, the curves for comm. camellia oil and 1% saline water were omitted, because they were entirely approximate to the curves of extd. camellia oil and dist. water, respectively, In each figure, P_i agrees almost wholly (tab. 2, col. 2). It will be seen from these diagrams, that the gradient of the curves for three kinds of whale oils is markedly larger than that of the other materials, at the earlier interval of t.

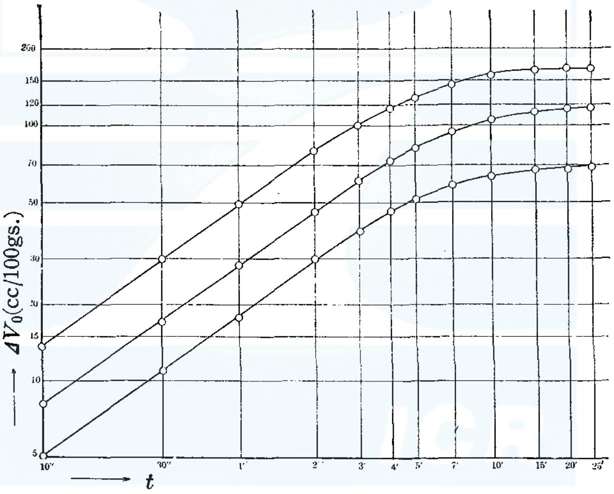

Fig. 7. Absorption Curves for 1.04% Saline Solution under various Pressure lebels. ΔV_0 : Volume of CO_2 (cc/100 gs.) absorbed. t : time (sec.). Pressure lebels (mm. Hg), from top to bottom : 2379–2135, 1650–1481, 935–835.

When we speak about a rapid or slow absorption of a material, it seems that the time required until saturation, is concerned. In other words, mean absorption velocity until saturation, is the point in question. It may be possible to characterize a material by this comparison. However, it seems that the velocity $\frac{d}{dt}(\Delta V_0)$ at the earlier interval of t indicates more acutely the difference between materials as to the absorption of gases, than their mean velocity.

In the following we will write $(\Delta V_0)'$ instead of $\frac{d}{dt}(\Delta V_0)$.

In figs. 6 to 16, each diagram shows the absorption curves of each material under various pressure lebels. It is clear, in these diagrams that $\log \Delta V_0$ in any of the curves is a linear function of $\log t$, in the interval where t is comparatively small. With increase of t, the curve shows a common tendency to bend down towards t-axis.

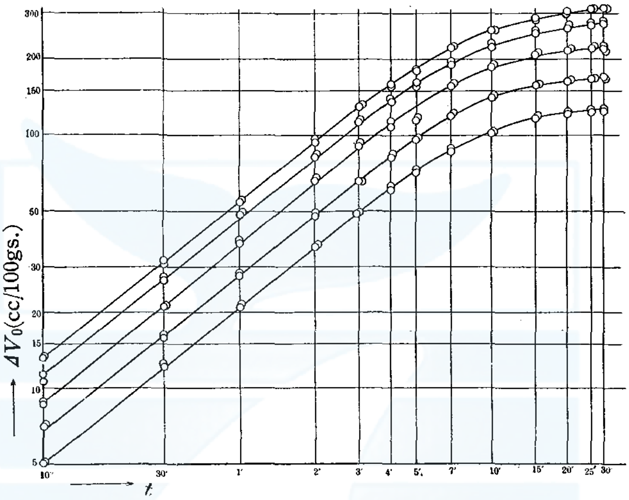

Fig. 8. Absorption Curves for Sperm Oil under various Pressure lebels. ΔV_0: Volume of CO_2 (cc./100 gs.) absorbed. t: time (sec.). Pressure lebels (mm.Hg) from top to bottom: 2364–1890, 2060–1644, 1640–1306, 1233–982, 927–738.

For the interval where linear relation holds, the equation can be stated in the form

$$\log \Delta V_0 = a + b \log t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

or

$$\Delta V_0 = a' t^b \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where ΔV_0 is the volume (in cc.) of CO_2 absorbed by 100 gs. of each material up to the time t (in sec.), a $(=\log a')$ and b will be parameters dependents upon the material and pressure lebel.

It may be offered some experimental formulae which would hold for these curves over the whole interval, in which the measurements were made. For example,

$$\Delta V_0 = a' t^b (1+\varepsilon)^{-t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

or

$$\Delta V_0 = a' t^b (1-\varepsilon t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where ε is a very small positive number. By making a suitable selection of ε, it is possible to obtain a good agreement between the observed and calculated values. However, as mentioned above, our purpose is to compare $(\Delta V_0)'$ of each material, in the earlier interval of t, and by which to characterize the materials. For this purpose, it is not necessary to be concerned with the equation (3) or (4), and is sufficient to do with the equation (2).

Table 2. Miscellaneous data from the Experiment

Materials	Pressure lebel		Time length of measurement (min.)	in formula $\Delta V_0=a't^b$			Ratio of $a'b$ to that of caster oil	
	P_i (mm.Hg)	P_f (mm.Hg)		a'	b	$a'b$		
Dist. Water	934*	834*	25	1.10	0.69	0.76	12.6	12.4 (mean)
	1240	1106		1.43		0.99		
	1656	1483		1.82		1.26	12.6	
	2061	1841		2.42		1.67		
	2382	2139		2.95		2.04	12.0	
ca. 1% Saline Solution	935*	835*	25	1.02	0.70	0.71	11.8	11.5
	1650	1481		1.61		1.12	11.2	
	2379	2135		2.80		1.96	11.5	
Sperm Oil	927	738	30	0.83	0.79	0.66	11.0	11.0
	1233	982		1.10		0.87		
	1640	1306		1.49		1.18	11.8	
	2060	1644		1.86		1.47		
	2364	1890		2.13		1.68	10.0	
Sperm Body Oil	928	750	30	0.70	0.78	0.55	9.2	9.1
	1234	995		0.94		0.73		
	1647	1322		1.23		0.96	9.6	
	2054	1655		1.54		1.20		
	2364	1902		1.83		1.43	8.4	
Whale Oil	930	755	35	0.44	0.80	0.35	5.8	6.1
	1228	995		0.59		0.47		
	1648	1343		0.81		0.65	6.5	
	2065	1677		1.05		0.87		
	2361	1912		1.26		1.01	5.9	
Olive Oil	932	753	100	0.21	0.80	0.17	2.8	2.8
	1649	1328		0.37		0.30	3.0	
	2375	1896		0.56		0.45	2.6	
Camellia Oil (extd.)	932	758	130	0.18	0.82	0.15	2.5	2.2
	1642	1331		0.28		0.23	2.3	
	2367	1926		0.39		0.32	1.9	
Camellia Oil (comm.)	936	757	130	0.17	0.82	0.14	2.3	2.0
	1648	1333		0.26		0.21	2.1	
	2366	1903		0.34		0.28	1.6	
Castor Oil	933	793	240	0.075	0.82	0.06	1.0	1.0
	1647	1365		0.127		0.10	1.0	
	2366	1958		0.205		0.17	1,0	
Oleic Acid	927	743	100	0.40	0.73	0.29	4.8	4.7
	1649	1319		0.67		0.49	4.9	
	2362	1889		1.03		0.75	4.4	
Oleyl Alcohol	936	786	60	0.24	0.81	0.19	3.1	3.6
	1651	1366		0.49		0.40	4.0	
	2364	1960		0.76		0.62	3.6	
Liquid Paraffin	932	802	180	0.12	0.82	0.10	1.7	1.7
	1651	1410		0.21		0.17	1.7	
	2362	2015		0.33		0.27	1.6	

* Pressure values are obtained by subtracting 42 mm.Hg, the saturated vapor pressure of dist. water at 35°C, from total pressure. In the case of ca. 1% saline solution, 40 mm.Hg is subtracted,

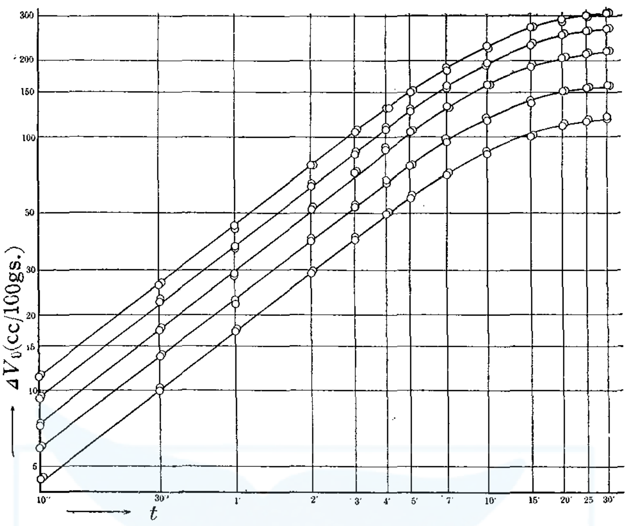

Fig. 9. Absorption Curves for Sperm Whale Body Oil under various Pressure lebels. ΔV_0: Volume of CO_2 (cc/100 gs.) absorbed. t: time (sec.). Pressure lebels (mm.Hg), from top to bottom: 2364–1902, 2054–1655, 1647–1322, 1234–995, 928–750.

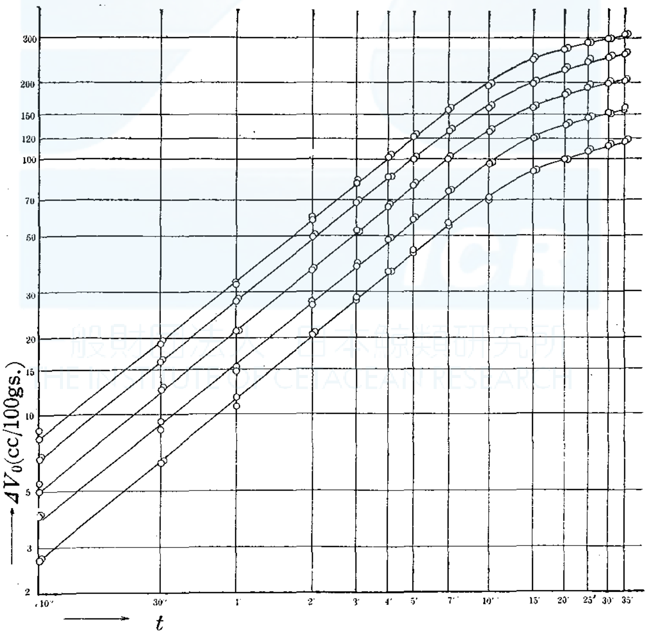

Fig. 10. Absorption Curves for Fin Whale Oil under various Pressure lebels. ΔV_0: Volume of CO_2 (cc/100 gs.) absorbed. t : time (sec.). Pressure lebels (mm.Hg), from top to bottom: 2361–1912, 2065–1677, 1648–1343, 1228–995, 930–755.

With 44 curves in fig. 6 to fig. 16, a' and b were determined according to the equation (1). The values of a' and b thus obtained for each material under various pressure lebels, are listed in col. 5 and 6 of tab. 2. In order to exmaine the difference between the value of log ΔV_0 obtained, and that calculated from equation (1), standard deviation from regression was computed for each curve. The mean value of them with 44 transformed curves was 0.010 with standard deviation of 0.003.

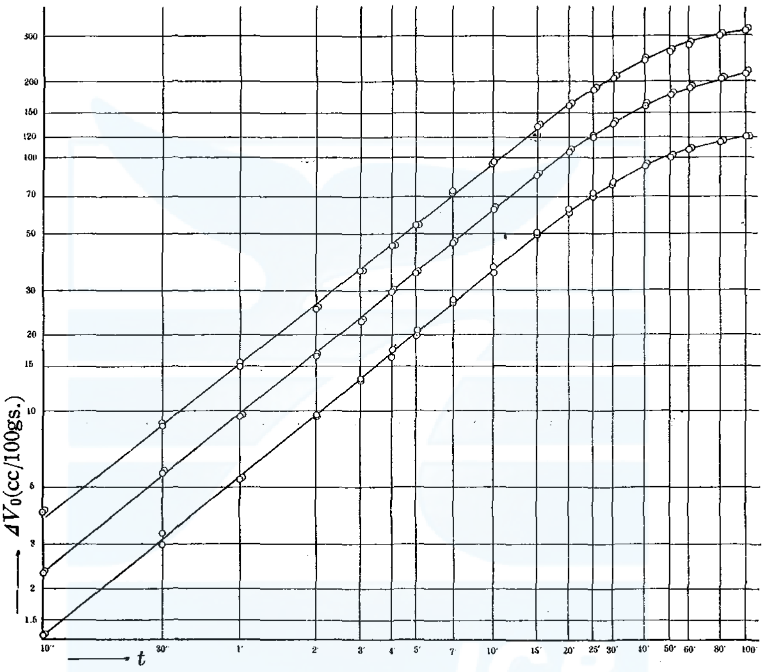

Fig. 11. Absorption Curves for Olive Oil under various Pressure lebels. ΔV_0: Volume of CO_2 (cc/100 gs.) absorbed. t : time (sec.). Pressure Lebels (mm.Hg), from top to bottom: 2375-1896, 1649-1328, 932-753.

From equation (2), we obtain

$$(\Delta V^0)' = a'bt^{b-1} \dots\dots\dots\dots\dots\dots\dots (5)$$

This equation (5) represents the absorption velocity of each material in the linear portion of the curve. If the value of b were a common constant for all materials, then the absorption velocity $(\Delta V_0)'$ will proportional to $a'b$ at any value of t, that is, $a'b$ will represent the velocity constant and therefore its magnitude under definite P_i, will characterize the materials. It is seen from col. 6 in tab. 2 that a constant b has been obtained within the same material irrespective of pressure lebel. But the value of b is not the same throughout all materials. It is the smallest (0.69) in dist. water and is 0.73 for oleic acid. With the exception of these, the values are 0.78 to 0.82 in all the other oily substances.

Owing to the unevenness of b, $a'b$ cannot represent a true velocity constant. But within the oily materials except water and oleic acid the values of b fairly approach to each other, then $a'b$ can stand for a velocity constant approximately, within these materials. It may be added that $a'b$ is $(\Delta V_0)'$ itself when $t=1$, and therefore that at the earliest interval of t, $(\Delta V_0)'$ of each material will be approximately proportional to its own $a'b$. In this sence, $a'b$ also is to be considered as a *measure* which characterizes a material, as to the absorption velocity of carbon dioxide. The values of $a'b$ are given in col. 7 of tabl. 2.

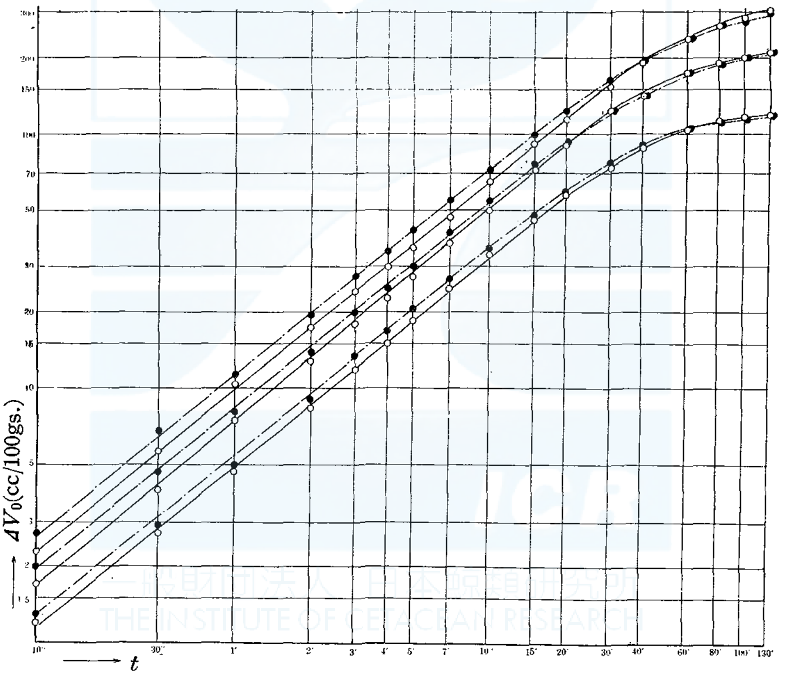

Fig. 12. Absorption Curves for Camellia Oil under various Pressure lebels.

—·—·—·— Extd. Pressure lebels (mm.Hg), from top to bottom: 2367-1926, 1642-1331, 932-758.

———— Comm. Pressure lebels (mm.Hg), from top to bottom: 2366-1903, 1648-1339, 936-757.

In fig. 17, the values of $a'b$ of each material have been plotted against the initial pressure, P_i. It seemed highly probable that the values of $a'b$ would indicate a linear regression against P_i. Since there are too few points which determine these straight lines, it is dangerous to make some conclusion immediately, but the fact that this tendency is observed in the majority of these materials, constitutes a strong basis for the assumption that a linear regression might hold for each material (with the exception of water, which showed a somewhat hyperbolic curve). In other materials, almost without exception, the curves showed linear regression. In this case, all these curves must pass the origin (0, 0), because under P_i (absolute pressure)$=0$, any absorption cannot occur and therefore the following equation will be hold for each curve in fig. 17.

$$a'b=\alpha P_i \text{..........................} (6)$$

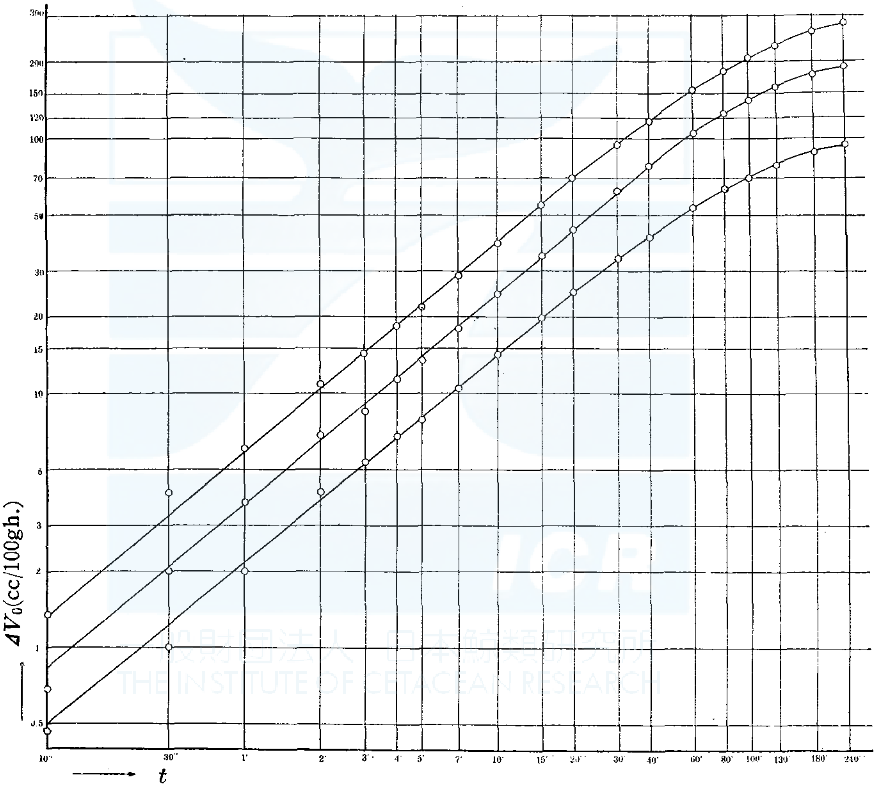

Fig. 13. Absorption Curves for Castor Oil under various Pressure lebels. $\varDelta V_0$: Volume of CO_2 (cc/100 gs.) absorbed. t: time (sec.), Pressure lebels (mm.Hg), from top to bottom: 2366–1958, 1647–1365, 933–793.

If this equation can be established for each material, α will be the better *measure* to characterize the material, than $a'b$. Because α is a parameter dependent only on the kind of materials. On the contrary $a'b$ dependent on the materials and also on the pressure lebels. The col. 8 in tab. 2 shows the ratio of $a'b$ for each material, under each P_i, to that of castor oil under corresponding P_i. It is clear from equation (6) that these values directly indicate the ratio of α, because, the ratio of α is equal to the ratio of $a'b$ at a definite P_i. Castor oil was chosen as the standard, since its $a'b$ happened to be the smallest. The values listed in col. 9 show fairly good agreement for all the materials. The value of ratio thus obtained, seems to be adequate *measure* to characterize a material as to the absorption velocity of gases.

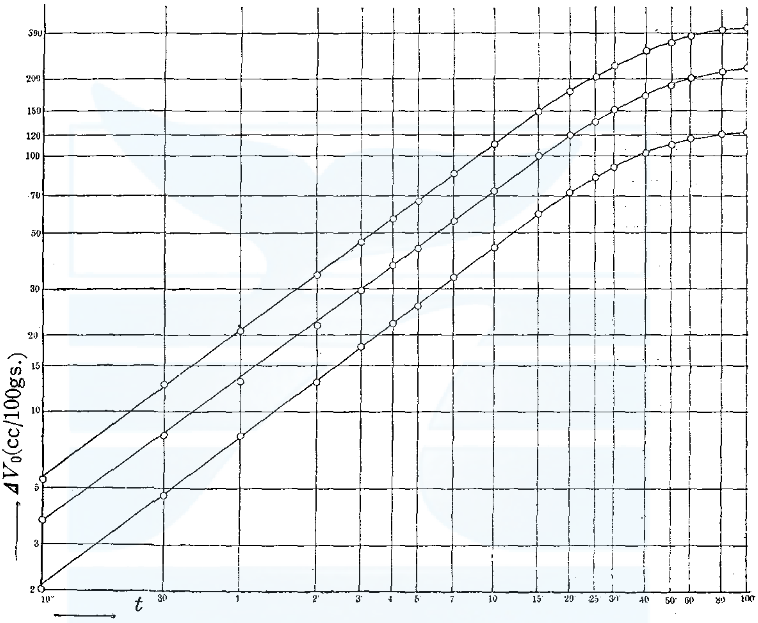

Fig. 14. Absorption Curves for Oleic Acid under various Pressure lebels. ΔV_0: Volume of CO_2 (cc/100 gs.) absorbed. t: tlme (sec.). Pressure lebels (mm.Hg), from top to bottom: 2362–1889, 1649–1319, 927–743.

It is clear that $a'b$ and α both quantities dependent upon the mechanical conditions, and the ratio of α may be also dependent on such. But it may be permitted to make hopefull assumption that this value is independent of the motion of the vessel. Because, if the conditions of the motion affect α of one material, the same conditions would probably affect α of the other materials, in the same degree.

Comment

The results of the present series of experiments seem to indicate that there is no great difference in the maximal quantity of carbon dioxide, absorbed by oils and oily substances. There is almost no difference, between the value of sperm oil after 30 mins. and that of olive oil after 100 mins. under every pressure lebels. If the duration of time required to reach the maximal quantity is not taken into account, the values of whale oils, vegetable oils and oleic acid do not show any great difference under corresponding pressure lebels. The maximal ΔV_0 of oleyl alcohol is fairly smaller than that of other oily substances. The maximal ΔV_0 of castor oil seems far smaller than that of the other oily substances, even after 240 mins., but it is still not clear whether this oil will show the same degree absorption as the other oily substances after a much longer period, or whether the solubility is characteristically small in this oil. On the contrary, the maximal ΔV_0 of water is clearly far smaller than that of others, being 1/2 or less under each of the pressure lebels.

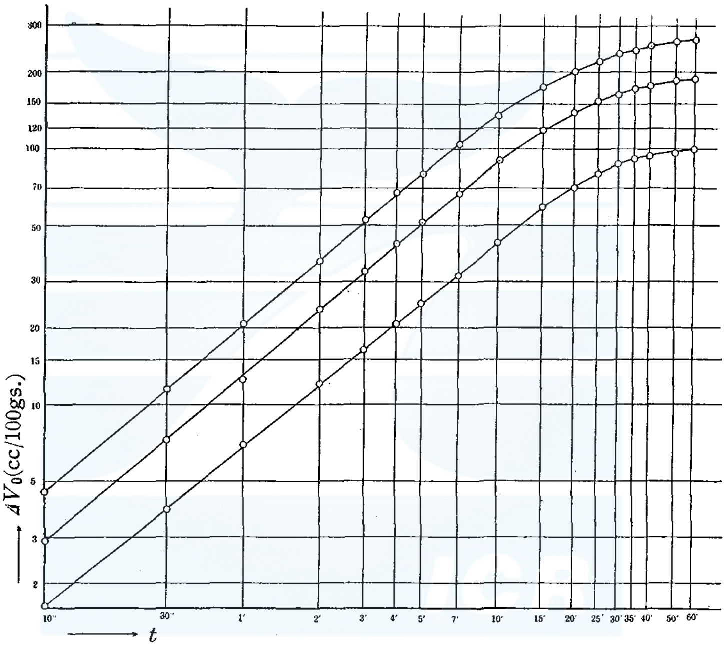

Fig. 15. Absorption Curves for Oleyl Alcohol under various Pressure Lebels. ΔV_0: Volume of CO_2 (cc/100 gs.) absorbed. t: time (sec.). Pressure lebels (mm.Hg), from top to bottom: 2364–1960, 1651–1366. 936–786.

On the other hand, it has been found that there exists a great difference in the absorption velocity of these materials. Taking castor oil as the standard, the velocity, 1 sec. after the outset is about 12 times faster in water, about 11 times in sperm oil, about 9 times in sperm whale body oil, and about 6 times in fin whale oil. In general, the absorption velocity of vegetable oils is small, the value of this ratio being about 2.8 in olive oil and about 2.0 in camellia oil. The striking fact revealed by these experiments is the prominently great velocity of carbon dioxide absorption by whale oils, compared to vegetable oils.

The relationship between viscosity and absorption velocity is not necessarily parallel. The viscosity of camellia oil is lower than that of olive oil, but the absorption velocity is smaller in the former. The viscosity of oleic acid is about the same as that of sperm oil, but their is a great difference in their velocity of absorption. The velocity at 1 sec. of the sperm oil is 2.4 times greater than that of oleic acid and about 3.0 times greater at 60 sec.. Therefore, low viscosity is not the sole factor for making the absorption velocity greater. The effect of viscosity on absorption velocity is not to be denied but some other physical properties ascribable to the molecular structure of the substance seem to be more responsible. Based on the assumption that a higher

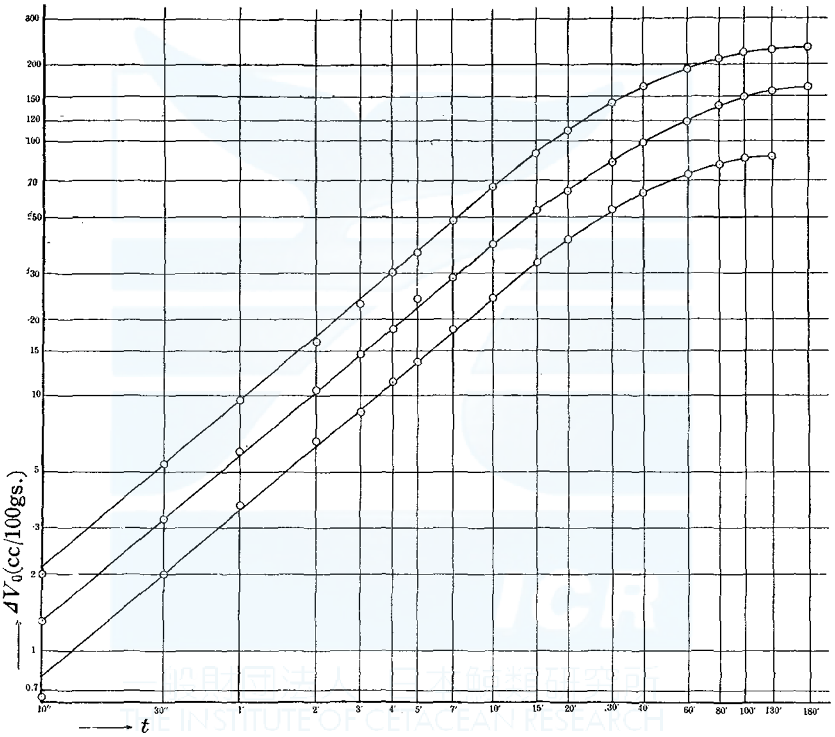

Fig. 16. Absorption Curves for Liquid Paraffin under various Pressure lebels. ΔV_0: Volume of CO_2 (cc/100 gs.) absorbed. t: time (sec.). Pressure lebels (mm.Hg), from top to bottom: 2362–2015, 1651–1410, 932–802.

alcohol, one of the components of wax, may be the one responsible, tests were made with oleyl alcohol but it was found that its absorption velocity was about the same as that of oleic acid.

The present study seems to be not very suggestive in the theoretical aspect of this question. The more theoretical expression of the data of this experiment will be

$$\frac{d}{dt}(\Delta V_0) = -\beta(A - \Delta V_0)$$

in this equation, A will represent the saturation quantity, which is a function of P, T and the kind of materials, and β will be a parameter, perhaps, only dependent on the kind of materials and not on P, at a definite T. If the measurements were carried out, under constant pressure, not under constant volume, this equation would probably hold for the experimental results. However, in the present study, this equation did not hold in this original form, any correction term is necessary to insert. Because A dose not become a constant but varies with time throughout one measurement. For this reason, the data were related to the experimental formula.

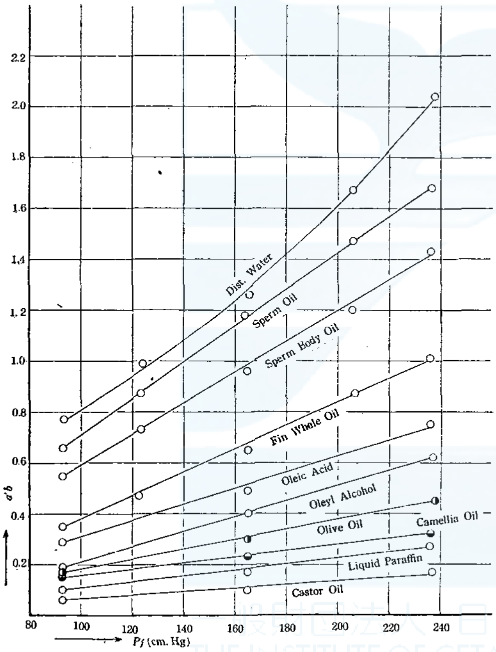

Fig. 71. Relationship between coefficient $a'b$ in the equation $\frac{d}{dt}(\Delta V_0) = a'bt^{b-1}$ and initial pressure P_i (cm.Hg).

Apart from this physical problem, the author wishes to take up the physiological significance of the fact that an oily substance of different velocity in carbon dioxide absorption is present in different living things. In this sense, the third physiological function of oils, besides its function as the energy source and insulation matter, seems to be suggested.

Summary

1) Absorption of carbon dioxide was studied with 12 kinds of substances, i.e., distilled water, ca. 1% saline solution, sperm oil, sperm

whale body oil, fin whale oil, olive oil, commercial and laboratory-extracted camellia oil, castor oil, oleic acid, oleyl alcohol and liquid paraffin.

2) Decrease of pressure, ΔP, caused by absorption was measured with each material at constant temperature (35°C) and constant volume, under five different pressure levels, i.e. under around 1, 2, and 3 atmospheric pressures and two intermediate levels. The volume of carbon dioxide absorbed, ΔV_0 (in cc./100 gs. of the material) at a standard state was obtained from ΔP.

3) From the experimental results obtained, following conclusions were drawn:

a) Maximal absorption of carbon dioxide by each material was found to be approximately proportional to pressure.

b) No great difference was found to exist in the maximal absorption of carbon dioxide between individual oils and oily substances. It was also found that the maximal absorption of carbon dioxide by water, under various pressure levels, was about one-half of that of oily substances.

c) There is a great difference in the velocity of carbon dioxide absorption between various materials which, when compared at the earliest velocity (velocity 1 second after outset), was in the decreasing order of distilled water, ca. 1% saline solution, sperm oil, sperm whale body oil, fin whale oil, oleic acid, oleyl alcohol, olive oil, camellia oil, liquid paraffin, and castor oil. The absorption velocity are strikingly great in the three kinds of whale oils and water.

4) As a *measure* for characterizing these materials in regard to the velocity of carbon dioxide absorption, the value of α or the ratio of α was proposed.

Acknowledgement

The author takes this opportunity to express his deep gratitude to Prof. Dr. T. Mori of the Tokyo University for his kind guidance and encouragement throughout the course of this work.