

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF MINES HELIUM ACTIVITY HELIUM RESEARCH CENTER

INTERNAL REPORT

RECALCULATION OF THE WORK OF Ph. v. JOLLY ON THE DENSITY OF OXYGEN

BY

Robert E. Barieau

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HELIUM RESEARCH CENTER

INTERNAL REPORT

RECALCULATION OF THE WORK OF Ph. v. JOLLY ON THE DENSITY OF OXYGEN "Die Veränderlichkeit in der Zusammensetzung der Atmosphärischen Luft"

Wiedemanns Annalen der Physik, Series (2), v. 6, pp. 520-544 (1879). Abhandlungen der Mathematisch-Physiklischen Classe der Koniglich Bayerischen Akademie der Wissenschaften, v. 13, Part 2, pp. 51-74 (1880).

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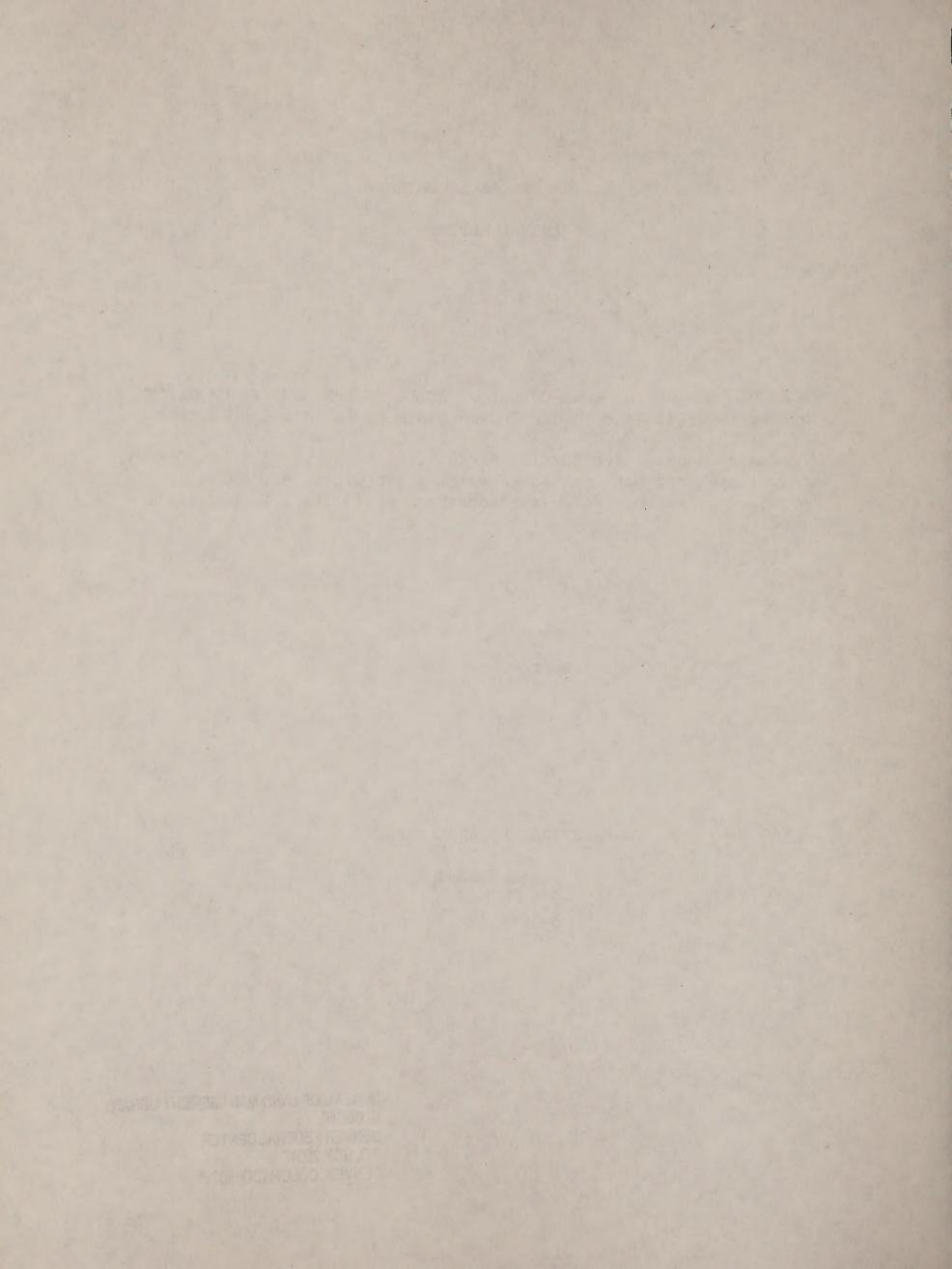
Robert E. Barieau

FUNDAMENTAL RESEARCH BRANCH

Project 4335

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Comparison with providenty constendant values

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RECALCULATION OF THE WORK OF Ph. v. JOLLY ON THE DENSITY OF OXYGEN

By

Robert E. Barieau^{1/}

ABSTRACT

The original data of Ph. v. Jolly on the density of oxygen has been recalculated, using the latest values of the necessary physical constants. The value obtained is

 $\rho = 1.429054 + 22 g/1$

with $g = 980.616 \text{ cm/sec}^2$.

INTRODUCT ION

The Helium Research Center is presently engaged in reviewing and recalculating all of the data that appear in the literature from which the value of the gas constant R is calculated. In this report I re-examined the work of Ph. v. Jolly on the determination of the density of oxygen at one atmosphere and at 0° C.

<u>1</u>/ Project Leader, Thermodynamics, Helium Research Center, Bureau of Mines, Amarillo, Texas.

Work on manuscript completed August 1964.

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Work on manageigt, completed August 1964

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Ph. v. Jolly determined the density of oxygen by weighing a globe, of about 1 liter capacity, filled with oxygen and then weighing it evacuated. During the filling and evacuation, the globe was completely surrounded by ice and water so that it was accurately at 0° C. The globe was evacuated to a pressure of 0.02 mm Hg.

The volume of the globe was determined by weighing the amount of water that would fill the globe at 0° C.

Oxygen was prepared by electrolysis. The gas was freed of ozone and hydrogen by passing through a glass tube filled with glass chips and heated to a red heat. The gas was also passed over potassium hydroxide and phosphorous pentoxide.

DETERMINATION OF THE VOLUME OF Ph. v. JOLLY'S GLOBE

Ph. v. Jolly determined the volume of his globe by determining the weight of water that filled the volume. The fact that he corrected the weight of water for the weight of air displaced indicates that the weight of the empty globe must have been determined with the stopcock open to the atmosphere. Under these conditions the relationship for the weight of water in vacuum is given by

$$M_{H_20} (1 - \frac{\rho_2}{\rho_{H_20}}) = M_2 (1 - \frac{\rho_2}{\rho_w}) - M_1 \frac{(1 - \frac{\rho_1}{\rho_w}) (1 - \frac{\rho_2}{\rho_g})}{(1 - \frac{\rho_1}{\rho_g})}$$
(1)

2 The rough decargined the density of oxygen by watehing a globe, of about 1 liter conscion, filled with unygen and then weighing it everabled for inc in filled with the evecation, the globe was completely exerteneeded by icc and terms at the fillent accurately at 6° C. the globe was evecanted to a presence of 0.00 and Hg

The volume of the globe was determined to weighted the ascence

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Fit. V. Jolty determined the volume of his grade by fateralnies the velote of water that itiled the volume. The fat daries he corrected the weight of water for weight of all displaced redifieres that the weight of the ampty group must have been deter afted with the stopport over to the stopping between these over directions the relationship for the weight of weat in recommon given

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In the above equation

$$M_{H_20} = mass of water$$

M₂ = mass of weights on balance when globe filled with water

= mass of weights on balance when globe filled with air and open to the atmosphere

ρ₁ = density of air during weighing of globe when filled with air

 $\rho_{\rm W}$ = density of weights

 ρ_g = average density of glass and stopcock in the globe ρ_{H_20} = density of water under conditions when the globe was weighed filled with water

 $1 - \frac{\rho_2}{\rho_{\rm H_20}}$ is the buoyancy correction factor for the weight of air displaced by the water. Ph. v. Jolly made this correction. $1 - \frac{\rho}{\rho_g}$ is the buoyancy correction factor for the weight of air displaced by the glass in the globe. As the ratio of two of these quantities is involved, the ratio only involves the change in the density of air between the two weighings. This correction is very small and was neglected by Ph. v. Jolly.

 $1 - \frac{\rho}{\rho_w}$ is the buoyancy correction factor for the weight of air displaced by the weights. In his determination of the weight of water, Ph. v. Jolly applied this correction.

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1 - ---- is the subsymmetry contraction factor for the weight of all ¹⁰M₂O as the horozone, contraction factor for the setter tion 1 - O as the horozone, contraction factor for the setter of the setter by the glass in the flate, we fare ratio of two of these quanticles is invelved; the tatte conjunctions the change in the destity of all between the two weightings. This contection is very setting and all between the two weightings. This contection is very setting and

 $1 - \frac{2}{R_{0}}$ is the busyand, derived the tartes for the satche of $\frac{2}{R_{0}}$ is the velocet by the velocet of the velocet of the velocet of the velocet of the set of t

Since Jolly gives the temperature of the air and the barometric pressure, I have recalculated the weight of water applying all corrections. In these calculations, I have assumed the density of the glass as being $\rho_g = 2.6$ g/ml. Ph. v. Jolly gives the density of his weights as being $\rho_w = 8.4$ g/ml. I have calculated the density of air from the equation²/.

2/ Barieau, Robert E.

The Density of Moist Air From O^o to Near 25^o C and Near Atmospheric Pressure. Helium Research Center Internal Report No. 36, August 1963.

$$\rho = \rho_0 \frac{T_0}{T} P (1 - 0.37807y) \frac{Z_0}{Z}$$
(2)

In this equation

- ρ is the density of air in g/liter
- ρ_{o} is the density of 0.04% CO₂, dry air at 0^o C and 1 atmosphere pressure

 $\rho_{0} = 1.2932 \text{ g/liter}$

P is the pressure in atmospheres, where 1 atmosphere is 76 cm of Hg at 0° C and in a gravitational field of 980.665 cm/sec² in the Potsdam system.

T is the absolute temperature

T is the absolute temperature of the ice point

y is the mole fraction of water vapor

Since hally gives the inequereras of the etc and the secnerric pressure. I have recentered the weight of water any of a all corrections in these recenterions. I have assumed the danalty of the grass as indicate established. The v. Lotty stress the density of the bis is the traction of a bis grad. I have esteblished the cost density of air traction of a bis grad. I have esteblished

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N is the presente in accomptores, where I accomptore is 76 cm of Hg at 0° C and in a presidentical child of 960 065 cm/sec to fine Pocedam system

T is the absolute temperature

the second se

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 $Z_{_{\scriptsize O}}$ is the compressibility factor of 0.04% CO $_{2},$ dry air at $0^{^{\rm O}}$ C and 1 atmosphere

Z is the compressibility factor of the gas at P and T

$$\frac{Z_{o}}{Z} = 1 - 0.000602 (P - 1) + (0.00254y + 0.0758y^{2})P$$

$$- (0.0000105 + 0.0000131y + 0.00131y^{2})tP$$
(3)

where in this equation, t is the temperature in °C.

The mole fraction of water in air saturated with water vapor was taken as (3)

(3) Reference (2) page 17

$$y_{sat} = 1.0042 \frac{P_s}{P}$$
 (4)

where P_s is the vapor pressure of pure water in atmospheres and P is the total atmospheric pressure in atmospheres. The vapor pressure of water was calculated from the equation given by Osborne, Stimson, and Ginnings (4)

 (4) Osborne, N. S., H. F. Stimson, and D. C. Ginnings. Thermal Properties of Saturated Water and Steam. J. Research NBS, v. 23, 1939, pp. 261-270. G is the compressibility factor of 0.02% CO2. dry air at

A is the comprossibility functor of the year at F and T

where is cuis equation, t is the conservatore in "C.

ves taken as (3)

(3) Seferance (2) page 1

where P is the vapor pressure of pute caler in atmospheros and P is the total atmospheric pressure in atmospheres The vapor pressure of sater was calculated from the equation given by Onbarias, Stimson, and Ginnings (4)

(4) Osborna, N., S., H. F. Stimaco, and D. C. Ginaings, Thermal Properties of Samurated Mater and Steam. J. Samarch 305, v. 23, 1939, pp. 281-270

$$\log_{10} P_{atm} = -3.142305 \left[\frac{10^3}{T} - \frac{10^3}{373.16} \right] + 8.2 \log_{10} \frac{373.16}{T}$$
(5)

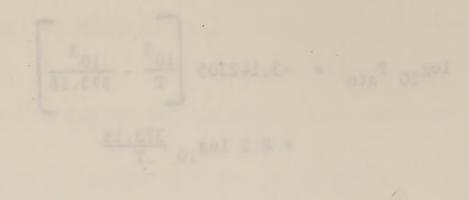
The density of liquid water was taken from the table of Tilton and Taylor (5)

(5) Tilton, L. W., and J. K. Taylor. Accurate Representation of the Refractivity and Density of Distilled Water as a Function of Temperature. J. Research NBS, v. 18, 1937, pp. 205-214.

Ph. v. Jolly weighed his globe filled with air, with the stopcock open to the atmosphere, first on the right pan of his balance and then on the left pan. The two values were 142.074331 g and 142.072500 g with a geometric mean of 142.073415 g. Jolly adds to this 0.001876 as the sum of the corrections to his individual weights, giving

$$M_1 = 142.075291 g$$

Atmospheric conditions during this weighing were $t = 7.1^{\circ}$ C, P = 721.57 mm Hg at 0° C under local gravity. In correcting the atmospheric pressure to standard gravity, I used $g_{local} = 980.7361$ cm/sec² and $g_{standard} = 980.665$ cm/sec².



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The sedally of figuid wether was baban from the celle of Vilcon and Tavior (5)

(5) Titter, L. M., and J. E. Tayinr. Accurate Supresentation of the Refrectivity and Density of Rightlied Whier as a Ferretica of Temperature. J. Remercick WE, 71 18, 1937, pp. 201-214.

Ph. v. Joli, weighed his globe inited with our, with the stopcock open to the statesphere. Sires on the right pan of his balance and then on the left pan. The two values were 142.074331 g and 102.072303 g with a germatric mean of 142.073413 g. Jolly ands co ester 0.001676 as the sum of the corrections to his individual weight.

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Attainspherit institutions during this weighting rate $r = 1.1^{\circ}$ C. F = 721.37 am lig at 0° C unime local proving. In correcting the atomospheric pressure to standard proving. I used though = 200.3351 cm/sec² and standard correct.

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Then P = $\frac{721.57 \times 980.7361}{760 \times 980.665}$

P = 0.949503 atmospheres.

Using the equations given previously, I calculate for the vapor pressure of liquid water at 7.1° C.

 $P_{c} = 0.0099495$ atmospheres.

Then y_{sat} (7.1° C) = 1.0042 × $\frac{0.0099495}{0.949503}$

or
$$y_{sat} = 0.0105226$$

Jolly does not give a hygrometer reading for this weighing, but he does give a value of 65% for the weighing when water was present in the globe. I will take a relative humidity of 65% for the first weighing also. I then calculate for the density of air

$$\rho_1 = 0.0011937 \text{ g/m1}$$

Then the true mass of the globe is

$$\frac{M_{1} \left(1 - \frac{\rho_{1}}{\rho_{w}}\right)}{\left(1 - \frac{\rho_{1}}{\rho_{g}}\right)} = 142.075291 \frac{\left(1 - \frac{.0011937}{8.4}\right)}{\left(1 - \frac{.0011937}{2.6}\right)}$$

 $= 142.075291 \times \frac{0.9998578929}{0.9995408846}$

: 142.120351 g

P = 0 949903 attoationers

Uning the equations group previously, I calculate for the vapor pressure of liquid water a: 7.1° C.

P. + D.9095495 atmosplieres

Then y_{gat} (7.1" G) = 1 0002 x G.0090493

Juliy does not give a breasesser reading for this weighing, but he does give a value of 057 for the weighing when water was present in the globe. I will take a relative humidity of 05% for the first weighting also. I then calculate for the density of air

Then the true mans of the alollo is

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$$\frac{m_1 (1 - \frac{m_1}{p_0})}{(1 - \frac{m_1}{p_0})} = \frac{142.0792291}{(1 - \frac{m_1}{p_0})} = \frac{(1 - \frac{000119337}{m_1})}{(1 - \frac{m_1}{p_0})}$$

acanonene o x reserved =

142.120331 g.

and with a density of 2.6 the glass occupies 54.7 ml.

When filled with water at 0° C, the globe and water weighed 1150.304760 g on the left pan and 1150.292000 on the right pan giving a geometrical mean of 1150.298380. To this, Jolly adds 0.001302 for the calibration of his weights to give

$$M_2 = 1150.299682 \text{ g}.$$

During this weighing, atmospheric conditions were $t = 6.4^{\circ}$ C, P = 721.3 mm Hg 0° C (local gravity), hygrometer = 65%. I calculate

$$P = \frac{721.3}{760} \times \frac{980.7361}{980.665}$$

P = 0.949148 atmospheres.

Using the equations given previously, I calculate for the vapor pressure of liquid water at 6.4° C

 $P_{c} = 0.0094821$ atmospheres.

Then

y(sat) (6.4° C) =
$$1.0042 \times \frac{0.0094821}{0.949148}$$

or

y(sat) = 0.0100321

and with a donaity of 2.6 the glass occupies 54.7 ml.

When filled with water at 0° 0, the globe and water weighed 1150.302700 g on the laft pan and 1130.292000 on the right pan giving a germetrical mean of 1130.298330. To this, Jolly adds 0.001302 for the birbherton of his weights to give

M3 = 1130.299682 8

Bus ing chis weighing, annougheric coultings were to 6.4° C. For 121.3 and dg G' C (incal gravity), hygrommter = 65%. I calculate

P = 0.959148 atmospheres.

Using the equations given previously, I calculate for the vapor pressure of liquid water at 5.4 C

P_ = 0.0094821 atmospheres.

TREN

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y(aat) = 0.0160321

and with the air 65% saturated with respect to water vapor, the mole fraction of water vapor then is

 $y = .65 \times .0100321 = 0.00652087.$

Then with $t = 6.4^{\circ}$ C, P = 0.949148 atmospheres and y = 0.00652087, I calculate for the density of air

 $\rho_2 = 0.0011964 \text{ g/ml}.$

Tilton and Taylor (6)

(6) Reference 5, page 213

give for the density of water at 6.4° C

 $\rho_{\rm W} = 0.9999546 \, {\rm g/ml}$

Then the expression for the mass of water, M_{H_2O} , is given by

$$M_{H_20} (1 - \frac{0.0011964}{0.9999546}) = 1150.299682 (1 - \frac{0.0011964}{8.4})$$
$$-142.075291 \frac{(1 - \frac{.0011937}{8.4})(1 - \frac{.0011964}{2.6})}{(1 - \frac{.0011937}{2.6})}$$

and with the air 65% saturated with respect to water vapor, the nole fraction of water vapor then is

.45 x .0100321 = 0.00832087.

Then with t = 6.4° C. F = 0.940166 atmospheres and

1m13 4801100.0 - et

Tilton and Taylor (6)

(6) Reference 5, page 213

give for the density of vatur at 6.4" .

1 - 0.9939520 g/ml

Then the expression for the mass of water, Nagor is given by

 $M_{H_20} \times 0.9988035457 = 1150.299682 \times .9998575714$

 $-142.075291 \times \frac{0.9998578929}{0.9995408846} \times 0.9995398462$

= 1150.135846 - 142.054953 = 1008.080893

Then M_{H2}O 1009.288461 g.

Jolly calculated

$$M_{\rm H_2O} = 1009.286871$$

which differs by 1.5 ppm from the value I have calculated.

Taking the density of water (7)

(7) Reference 5, page 213

at 0° C as 0.9998676 g/ml, I calculate for the volume of Jolly's globe at 0° C

$$V = \frac{1009.288461}{0.9998676}$$
$$= 1009.4221 \text{ m1}$$

or

=

or

which differs by 1.5 ppm from the value I have calculated. Taking the decairs of water (7)

(7) Reference 5, page 213

at C' C as 0.9998676 g/ml, 1 calculate for the volume of Jolly's globe at C' C

DETERMINATION OF THE MASS OF OXYGEN

Jolly determined the mass of oxygen in the following way. He completely surrounded the globe with ice and water and admitted oxygen until the globe was filled at atmospheric pressure. After equilibrium, the barometer was read and the stopcock closed. The globe was then removed and weighed. The globe was then returned to the ice bath and evacuated to 0.02 mm of Hg, the stopcock closed and the evacuated globe was weighed.

The weighings were carried out in the following way. Jolly had a tare globe that had the same external volume as his oxygen weighing globe, to within 0.06 ml. His weighing globe and tare globe were placed on the opposite pans of the balance. When his weighing globe was filled with oxygen, weights were necessary on the pan with the tare globe. When the weighing globe was evacuated, weights were necessary on the pan with the weighing globe. To correct for inequality of the balance arms, each weighing was done twice, interchanging the objects on the balance pans. Jolly applied corrections for the difference between the nominal value and actual value of his weights.

Let M_T be the mass of the tare globe and its contents
Let M_G be the mass of the globe to be filled with oxygen
Let V_T be the external volume of the tare globe during the
weighing

Let V_{G} be the external volume at the time of weighing of the globe to be filled with oxygen

DEFINIMITYAT TOR OF THE MASS OF OXYORM

Jolly determined the mass of oxygen in the folicwing way. He completely surrouslad the globe with ice and vater and admitted oxygen usell the globe was filled at accompletic pressure. After equilibrium, the bereseter was read and the stopcock closed. The globe was then removed and weighed. The globe was then returned to the ice bath and evacuated to 0.02 mm of Hg, the stopcock closed and the syncusted to 0.02 mm of Hg, the stopcock

The weighings were carried out in the following way. Jolly had a tere globe that had the same external volume as his waygen weighing globe, to within 0.06 ml. His weighting globe and tere globe were placed on the opposite gams of the balance. Much his weighing globe was tilled with owygen, weights were mersonery on the pan with the tere globe. When the weighing globe was avecuated, weighte were necessary on the pan with the weighing globe to correct for inequality of the balance arms, each weighing was done twice, interchanging the objects on the balance pans. Jolly applied corrections for the difference between the nominal value and actual value of his weighter.

Let M_T be the name of the tare globe and its contents bet M_C he the mass of the globe to be filled with exygen let V_T be the supermal volume of the tare globe during the weighting

het V he the external volume at the time of weighing of the

Let ρ_{air} be the density of the air at time of weighing Let ρ_w be the density of the weights

Let M_W be the mass of weights that bring the balance to equilibrium and

Let g be the mass of oxygen in the main globe.

Let the first weighing be with the main globe filled with oxygen. When the balance is in equilibrium the following equation applies.

$$M_{G} + g_{1} - V_{G_{1}} \rho_{air_{1}} = M_{T} - V_{T_{1}} \rho_{air_{1}} + M_{W_{1}} (1 - \frac{\rho_{air_{1}}}{\rho_{W}})$$
(6)

Let the second weighing be when the main globe is evacuated. Then at equilibrium

$$M_{G} + g_{2} - V_{G_{2}} \rho_{air_{2}} + M_{W_{2}} (1 - \frac{\rho_{air_{2}}}{\rho_{w}}) = M_{T} - V_{T_{2}} \rho_{air_{2}}$$
 (7)

Then

$$g_{1} - g_{2} = M_{W_{1}} \left(1 - \frac{\rho_{air_{1}}}{\rho_{W}}\right) + M_{W_{2}} \left(1 - \frac{\rho_{air_{2}}}{\rho_{W}}\right) + \left(V_{G_{1}} - V_{T_{1}}\right) \rho_{air_{1}} - \left(V_{G_{2}} - V_{T_{2}}\right) \rho_{air_{2}}$$
(8)

This equation includes all buoyancy corrections.

Jolly did not give the temperature, pressure, and relative humidity of the air during any of his weighings. We can only assume a constant value for the density of air. Let p_{alr} be the density of the sir at time of weighting Let p_{c} be the density of the weights

Let No the mass of weights that bring the balance to

Let g bu the mass of oxygon in the main globa

Let the first weighing be with the main globe filled with oxygen. What the balance is in equilibrium the following equation applies

$$M_{G} + S_{I} - V_{G_{I}} P_{aXr_{I}} - M_{T} - V_{T_{I}} P_{aIr_{I}} + M_{w_{I}} \left(1 - \frac{P_{aIr_{I}}}{P_{w}}\right)$$
 (6)

Let the second weighing be when the main globe is evacuated. Then at equilibrium

$$x + g_2 - V_{G_2} g_{abr_2} + M_{a_2} \left(1 - \frac{a_{br_2}}{a_{br_2}}\right) = M_1 - V_{T_2} g_{atr_2}$$
(2)

Then

$$M_1 = B_2 = M_{w_1} \left(1 - \frac{a_{11}}{\rho_{w}}\right) + M_{w_2} \left(1 - \frac{a_{11}}{\rho_{w}}\right),$$
 (8)

This equation includes all budyancy corrections,

Joily did not give the tarperature, pressure, and relative humidity of the air during any of his weighings. We can only essure a constant value for the density of air. $V_{\rm T}$ and $V_{\rm G}$ will be a function of the temperature and also a function of the pressure difference between the inside and outside of the globe.

I assume this variation may be expressed by

$$V_{T} = (V_{0} + \delta)(1 + \alpha t)$$
(9)

$$V_{\rm G} = V_{\rm o} (1 + \alpha t) (1 + \beta \Delta P)$$
(10)

where ΔP is the pressure difference between inside and outside. Then

$$V_{G} - V_{T} = V_{O} (1 + \alpha t) \beta \Delta P - \delta (1 + \alpha t)$$
(11)

For the first weighing, we assume $\Delta P = 0$. Then

$$g_1 - g_2 = (M_{W_1} + M_{W_2})(1 - \frac{\rho_{air}}{\rho_W})$$
 (12)

$$-V_{o}(1 + \alpha t_{2}) \beta \Delta P_{2} \rho_{air}$$

where

$$\Delta P_2 = P_{\text{inside}} - P_{\text{outside}}$$
(13)

during the time of the weighing when the main globe is evacuated.

The correction term $V_0(1 + \alpha t_2) \beta \Delta P_2 \rho_{air}$ has been called the correction for the contraction of the globe. Jolly neglected this correction. The necessity for making this correction was first

V_L and V_C will be a runceion of the tangesstare and size a function of the pressure difference between the inside and outeide of the globa.

L ampune this vertation may be expressed by

$$V_{\rm T} = (V_{\odot} + \delta)(1 + \infty)$$
 (3)

$$V_{G} = V_{0} (1 + at) (1 + BAD)$$
 (10)

where AF is the prossure difference between include and outside.

$$V_{G} = V_{T} = V_{0} (1 + \alpha c) = \Delta P - c (1 + \alpha c)$$
 (11)

For the first weighing, we assume AP = 0.

madl

(12)

Where

ducing the time of the weighter when the main globe is everoated,

The correction term $V_{c}(1 + \alpha t_{c})$ EAP₂ one has been called the correction for the contraction of the globa. Jolly neglected this correction. The mercessicy for making this correction was first

pointed out by Lord Rayleigh (8)(9)

- erlocked the fact that in weighing his water, Jolly used gold
- (8) Lord Rayleigh. On the Relative Densities of Hydrogen and Oxygen. Preliminary Notice. Proc. Roy. Soc. (London), v. 43, 1888, pp. 356-363.
- (9) Lord Rayleigh. On the Relative Densities of Hydrogen and Oxygen. Preliminary Notice. The Chemical News, v. 57, 1888, pp. 73-75.

The factor $(1 - \frac{\rho_{air}}{\rho_{w}})$ is the correction for air buoyancy on the weights. Ph. v. Jolly seems to have neglected this correction in determining the weight of his gases; while he, as we have seen, applied a buoyancy correction to his weights in determining the weight of water that filled his globe at 0° C. In regard to this point Lord Rayleigh says (10)

(10) Lord Rayleigh. II On the Densities of the Principal Gases. Proc. Roy. Soc. (London), v. LIII, 1893, pp. 134-149. Footnote on page 140.

"In v. Jolly's calculations the buoyancy of the weights seems to be allowed for in dealing with the water, and neglected in dealing with the gases. If this be so, the result would be affected with a slight error which, however, far exceeds any that could arise pointed out by Lord Rayleigh (8) (9).

- (8) Lord Eagleigh. On the Relative Densities of Hydrogen and Oxygen. Freitminary Nortce. From Rays Sec. (London), v. 43, 1888, pp. 355-363.
- (9) Lord Reviergh. On the Relative Demotifies of Bydrogen and Gaygen. Freifminary Notice The Chemical News, v. 57, 1688, pp. 73-75.

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(10) Lord Rayleigh. II On the Densities of the Frincipal Gases. Free. Roy. Soc. (Londen), v. LILL, 1893, pp. 134-149. Footmate on page 140.

"In a dolig's caldulations the huspacey of the weights seems to be allowed for in dealing with the water, and neglected in dealing with the gases. If this he so, the result would be affected with a slight error which, however, far exceeds any that could arise

- 10

from neglecting buoyancy altogether." Lord Rayleigh evidently overlooked the fact that in weighing his water, Jolly used gold plated brass weights, while in weighing his gases, he used platinum weights. Under these conditions, neglecting buoyancy altogether introduces an error of 87 ppm low in the density of oxygen, while applying the buoyancy correction to the water determination and neglecting it in the determination of weight of gas, introduces an error of 56 ppm high in the density of oxygen. Applying both buoyancy corrections and assuming a 10% uncertainty in the density of air during the gas weight determinations, reduces the uncertainty in the density of oxygen to 5 ppm. I have therefore applied a buoyancy correction for the weights in the determination of the mass of oxygen. In these calculations, I have taken the density of air as being 0.0012 g/ml.

I reproduce below the data on the weight of oxygen given by Jolly in his paper.

	Gew. d. Kolbens 0°		Kolben O ^o 0.02 mm	Gew. d	Gew. d.O	
1	Bar.	K = T +	K = T -	Bar.	Gew.	0° 760 mm
I II IV V VI VII	714.45 711.30 715.02 720.42 722.02 706.93 693.79	0.083799 0.077913 0.074904 0.095182 0.098103 0.069659 0.044552	1.272183 1.272187 1.272180 1.272224 1.272380 1.272188 1.272222	714.43 711.28 715.00 720.40 722.000 706.91 693.77	1.355982 1.350100 1.347084 1.367406 1.370483 1.341847 1.316774	1.442470 1.442579 1.442489 1.442570 1.442571 1.442562 1.442478
	vidently	there is a	Cypotraphie	-	Mittel	1.442545

TABLE 1. - Original data published by Jolly

from magineting buoyams altoguither." Losd Habitaip ovidently overheeked the fact that in weighing his water, Juliy uned gold plated trans amights, while in weighing his games, he used platiman weights. Under these predittions, magineting huoyams altogether introducer as struer of 87 ppm low in the density of outpen, while applying the huoyams contaction to the vater intermination and neglecting it in the determination of weight of gam, introduces an error of 58 ppm high in the density of gam, introboth huoyams contections and stausing a 10% uncertainty is the manetics of alt curing the gam weight determinations, reduces the applited a huoyamer correction for the weights in the determination of the mass of oragen. In the stausing a 10% uncertainty is the density of alt curing the gam weight determinations, there taken the applited a huoyamer correction for the weights in the determination

I reproduce being the data on the Weight of onygen given by

		1.272180 1.272224 1.272280 1.272288		IIII IIII V V V VIIII IV	

ſ

The second column, headed Bar., is evidently the barometric pressure reduced to mm of Hg at 0° C under local gravity conditions. The third column gives the weight that must be added to the tare to balance the globe filled with oxygen to a pressure equal to the barometric pressure. The fourth column gives the weights that must be added to the evacuated globe to balance the tare. These are the data that I have called M_{w1} and M_{w2}.

Evidently, column 6 is nothing but the sum of columns 3 and 4, that is $M_{w_1} + M_{w_2}$.

The fifth column is the barometric pressure minus 0.02 mm, which was the pressure when the globe was evacuated.

Column seven is evidently column six times 760, divided by the pressure listed in column five. In table 2, I give this number calculated from columns five and six and compare it with Jolly's value given in column seven.

	TABL	E 2 <u>Comp</u>	arison of calc	ulated data	
	$\triangle \mathbf{P}$	$M_{w_1} + M_{w_1}$	$(M_{W_1} + M_{W_2})$	<u>760</u> Jolly ΔΡ	Δ
		-			
I	714.43	1.355982	1.442473	1.442470	+.000003
II	711.28	1.350100	1.442577	1.442579	000002
· III	715.00	1.347084	1.431866	1.442489	010623
IV	720.40	1.367406	1.442572	1.442570	+.000002
V	722.00	1.370483	1.442614	1.442571	+.000043
VI	706.91	1.341847	1.442622	1.442562	+.000060
VII	693.77	1.316774	1.442478	1.442478	.000000

Evidently there is a typographical error in connection with experiment III and possibly with experiments V and VI.

The second column, handed dar , is evidencip the barometric pressure reduced to us of Hg at 0° C under local gravity couldtions. The third column gives the weight that must be added to the tare to balance the globe Stilled with oxygen to a pressure equal to the barometric pressure. The fourth column gives the weights that must be added to the evacuated globe to balance the tare. These are the data that I have called M and M

Evidently, column 5 is mothing but the sum of columns 3 and 4, that is $M_{v_1} + M_{v_2}$.

The fifth column is the barometric pressure minus 0.02 mm, which was the pressure when the globe was evecuated.

Column seven is evidently column six times 760, divided by the pressure listed in column five. In table 2, 1 give this number calculated from columns five and six and compare it with Jolly's value given in column seven.

Evidently there is a typographical error in connection with experiment III and possibly with experiments V and VI.

101

If $M_{w_1} + M_{w_2} = 1.357084$ for experiment III, then

$$\frac{(M_{w_1} + M_{w_2})760}{715.00} = 1.442495.$$

This is to be compared with Jolly's tabulated value of 1.442489. This is sufficiently close to my calculated value that for experiment III, I take $M_{W_1} = 0.084904$.

I then find the values given in table 3.

	TABLE 3 Accept	ted values of M + M W1 W2	
	$M_{w_1} + M_{w_2}$	$(M_{w_1} + M_{w_2}) \frac{760}{\Delta P}$	Jolly
I II IV V VI VII	1.355982 1.350100 1.357084 1.367406 1.370483 1.341847 1.316774 Mean	$ \begin{array}{r} 1.442473\\ 1.442577\\ 1.442495\\ 1.442572\\ 1.442614\\ 1.442622\\ 1.442622\\ 1.442478\\ 1.4425473\\ \end{array} $	$\begin{array}{r} 1.442470\\ 1.442579\\ 1.442579\\ 1.442489\\ 1.442570\\ 1.442571\\ 1.442562\\ 1.442478\\ 1.4425313\end{array}$

At the bottom of table 3, I give the mean of the values calculated by me and the mean of the values tabulated by Jolly. However, Jolly gives the mean of the values tabulated by him as 1.442545. This essentially agrees with the mean of my calculated values and not with the mean of his tabulated values. I have therefore concluded that the values given in column 2 in table 3 are the values to If M + M = 1.357084 for experiment 111, then

$$\frac{(M_{w_1} + M_{w_2})760}{715.00} = 1.442495.$$

This is to be compared with Jolly's tabulated value of 1 Marage. This is sufficiently close to my calculated value that for experiment III. I take $M_{ij} = 0.084904$.

I chen find the values given in table 3.

dilar				
		1.355982 1.355982 1.357084 1.357084 1.3570683 1.370483 1.370483 1.316774	I II IV VI VI VI VI	

At the bottom of table 3, 1 give the mean of the values calculated by me and the mean of the values tabulated by Joliy. However, Joliy gives the mean of the values tabulated by him as 1.342545. This essentially agrees with the mean of my calculated values and not with the mean of his tabulated values. I have therefore concluded that the values given in column 2 in table 3 are the values to

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be used in calculating the weight of oxygen, $g_1 - g_2$ of equation (12). These values must be corrected for the air buoyancy on the platinum weights and for the contraction of the globe.

For the buoyancy correction, I have taken the density of air as 0.0012 g/ml and the density of platinum as 21.45 g/ml. The factor

$$-\frac{\rho_{air}}{\rho_{w}} = 1 - \frac{0.0012}{21.45}$$

= 0.99994406

must be multiplied by each of the values of (M + M) listed in $W_1 = W_2$ table 3.

In order to make the correction for the contraction of the globe, it is necessary to know the value of β , used in equations (10) and (12). This coefficient has been determined by Moles and Miravalles (11) (12),

(11) Moles, E. and R. Miravalles

A Cerca de la Compresibilidad de los Matraces vacios en la Determination de gases (The Compressibility of Evacuated Flasks in the Determination of Gas Densities) Anales de la Sociedad Espanola de fisica y quimica, v. 20, 1922, pp. 104-116. be used in calculating the satisfit of oxygan. 21 - 22 of equation (12). These values must be corrected for the air broyancy on the platinum weights and for the contraction of the globe.

For the buoyancy corraction, I have laken the density of air as 0.0012 g/ml and the density of platium as 21.45 g/ml. The factor

 $-\frac{p_{alc}}{p_{w}} = 1 - \frac{0.0012}{21.95}$

- 0.99996.05

must be multiplied by each of the values of $(M_{\mu} + M_{\mu})$ insted in

Cable J.

In order to make the correction for the contraction of the globe, it is necessary to know the value of 8, used in equations (10) and (12). This coefficient has been determined by Moles and Miravalles (11) (12).

(11) Moles, E, and R. Miravalles

A Cence de la Comprestibilidad de los Matraces vacios en la Determination de gases (The Compressibility of Evacuated Flacks in the Determination of Gas Donattics) Anales de la Sociedad Espanola de Fields y goimica, y 20, 1922, pp. 104-115. Sur la Contraction des Ballons Vides dans les Mesures de la Densite de Gas (On the Contraction of Empty Flasks in Measurement of gas Densities) J. de Chemie Physique, v. 21, 1924, pp. 1-9.

who made measurements on many different globes. They give

$$3(atm^{-1}) = \frac{V}{w} \times 15.5 \times 10^{-6}$$
 (14)

where V is the volume of the flask in ml and

w is the weight of the flask in grams For Jolly's flask

V = 1009.42 m1w = 142.12 gm V/w = 7.103

So that

$$\beta = 1.101 \times 10^{-4} (atm^{-1})$$

Since this correction is a small correction, I have taken $V_0(1 + \alpha t_2)$ in equation (12) as being

 $V_{0}(1 + \alpha t_{2}) = 1009.4 + 54.7$

= 1064.1 ml.

Orygen Gas) Journal de Chimis Physique at fevus Generals des Colluides, v. 19, 1921, pp. 150-120. Sur la Contraction des Ballons Vides dans im Mesures de la Baneite de Ons (OH the Contraction of Empty Flasks in Messurewent of gas Donatties) J. de Chemie Nysique, v. 21, 1924, op 1-9.

who made measurements on many different globes. They give

where V is the volume of the Hask in all and

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Ror Joldy's Flash

V = 1005.42 ml
v = 142.12 gm
V/w = 7.103

So that

("mis) "01 × 101.1 - 8

Since this correction is a scall correction, I have taken

V.(1 + atg) = 1009.4 + 34.7

10 1.080/ - -

18

54.7 is the volume occupied by the glass in the flask. I have taken ΔP_2 in equation (12) as being minus the pressure given in column 2 of table 2, divided by 760.

The calculations of the weights of oxygen are summarized in table 4. $g_1 - g_2$ was calculated using equation (12).

TABLE 4 Calculation of mass of oxygen					
	$(M_{w_1} + M_{w_2})(1 - \frac{\rho_{air}}{\rho_w})$	$-V_0(1 + \alpha t_2)\beta \Delta P_2 \rho_{air}$	^g 1 - ^g 2		
I	1.355906	0.000132	1.356038		
II	1.350024	0.000132	1.350156		
III	1.357008	0.000132	1.357140		
IV	1.367330	0.000133	1.367463		
V	1.370406	0,000134	1.370540		
VI	1.341772	0.000131	1.341903		
VII	1.316700	0.000128	1.316828		

The values of the correction for the contraction of the globe, represent a correction of 0.00014 in the final value of the density of oxygen. Lord Rayleigh (13)

(13) Reference 10, page 147

estimated this correction to be 0.00032, while Moles (14)

(14) Moles, E.

Etude Critique des Valuers Modernes de la Densite du gaz
Oxygene (Critical Study of Modern Values of the Density of
Oxygen Gas) Journal de Chimie Physique et Revue Generale des
Colloides, v. 19, 1921, pp. 100-120.

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column 2 of rable 2, divided by 760.

The calculations of the weighte of exygen are summarized in

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		1.355906	
		1.350024	
		1.357008	

	181000.0-	

The values of the correction for the contraction of the globe, represent a correction of 0.00014 in the final value of the density

(13) Reference 10, page 147

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(14) asion this deression to be 0.00032, while Moles (14)

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Rtude Critilgue des Valgers Hadernes de la Densite du gaz Onygene (Critical Study of Hodern Values of the Density of Oxygen Gas) Journal de Chimis Fhysique et Revue Generale das Calloides, v. 19, 1921, pp. 100-120.

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estimated it to be 0.00020, which in a later paper by Moles and Gonzalez (15),

(15) Moles, E. and F. Gonzalez

Nouvelle Revision de la Densite Normale du Gaz Oxygene. (New Revision of the Normal Density of Oxygen Gas.) Journal de Chimie Physique, v. 19, 1921, pp. 310-323. Footnote 2 on page 322.

was changed to 0.00016.

CALCULATION OF THE DENSITY OF OXYGEN

In this section I derive the formula necessary to calculate the density of oxygen at 0° C and at 1 atmosphere where in this section, 1 atmosphere is defined as 760 mm of Hg at 0° C under the conditions of local gravity.

In each experiment, the globe contained g_1 grams of oxygen at a pressure P_1 , near 1 atmosphere and at a volume V_0 . When evacuated to the pressure P_2 , the globe contained g_2 grams of oxygen, in the volume V_0 where

$$V_{2} = V_{0} [1 + \beta (P_{2} - P_{1})]$$
(15)

I apply the exact equations

$$P_{1}V_{0} = \frac{g_{1}RT_{0}Z_{1}}{M}$$
(16)

estimated it to be 0.00020, which in a later paper by Moles and Gonzales (15),

(15) Moles, E. and F. Gonzalez

Nouvelle Revision de la Densite Normale de Gas Osygene. (New Revision of the Mormal Density of Osygen Gas.) Journal de Chimie Physique, v. 19, 1921, pp. 310-323. Fobinote 2 on page 322.

was changed to 0.00016.

CALCULATION OF THE DERBITY OF OXIGEN

In this anotion I derive the formula becessing to establate the density of oxygen at G c and at I atmosphere where in this section. I about phere is defined as 260 mm of Eg at G C under the condicions of foost pravity.

Is each experiment, the globe contained g_1 grame of oxygen at a pressure P_1 , near 1 atmosphere and at a volume V_0 . When evacuated to the pressure P_2 , the globe contained g_2 grams of oxygen, in the volume V_0 where

$$v_2 = v_0 [1 + B (P_2 - P_1)]$$
 (15)

I seply the exact equations

$$P_1 V_1 = \frac{g_1 R_1 g_1}{M}$$
(16)

23

$$P_2 V_2 = \frac{g_2 RT_0 Z_2}{M} = P_2 V_0 [1 + \beta (P_2 - P_1)]$$
(17)

where M is the molecular weight of oxygen and Z is the compressibility factor. Then

$$\frac{P_1}{P_2} = \frac{g_1 Z_1}{g_2 Z_2} [1 + \beta (P_2 - P_1)]$$
(18)

or

$$g_{2} = g_{1} \frac{Z_{1}}{Z_{2}} \frac{P_{2}}{P_{1}} [1 + \beta (P_{2} - P_{1})]$$
(19)

Thus

$$g_1 - g_2 = g_1 \left(1 - \frac{Z_1}{Z_2} \frac{P_2}{P_1} \left[1 + \beta (P_2 - P_1) \right] \right)$$
 (20)

and

$$g_{1} = \frac{g_{1} - g_{2}}{1 - \frac{Z_{1}}{Z_{2}} \frac{P_{2}}{P_{1}} [1 + \beta (P_{2} - P_{1})]}$$
(21)

Now let g_{760} be the grams of oxygen that would be in the globe at a pressure of 760 mm of Hg at 0° C and with the barometric pressure the same. With P_{760} representing this pressure, we have

$$\frac{P_1}{P_{760}} = \frac{g_1}{g_{760}} \frac{Z_1}{Z_{760}}$$
(22)

$$P_2 V_2 = \frac{q_2 RT_0 2_2}{M} = P_2 V_0 (1 + B(P_2 - P_1))$$
 (17)

where M is the molecular weight of oxygen and Z is the compressibility factor. Then

$$\frac{p_1}{p_2} = \frac{g_1}{g_2} \frac{z_1}{z_2} \left[1 + g (p_2 - p_1) \right]$$
(13)

10

$$\mathbf{E}_2 = \mathbf{E}_1 \frac{\mathbf{Z}_1}{\mathbf{Z}_2} \frac{\mathbf{P}_2}{\mathbf{P}_1} \left(1 + \mathbf{B}(\mathbf{P}_2 - \mathbf{P}_1) \right)$$
(19)

Enul1

$$s_1 - s_2 = s_1 \left(1 - \frac{z_1}{z_2} \frac{r_2}{r_1} \left(1 + g \left(p_2 - p_1^{\prime} \right) \right) \right)$$
 (20)

bas

$$= \frac{g_1 - g_2}{1 - \frac{2}{2_2}} \frac{g_1 - g_2}{g_1} (1^2 + g(p_2 - p_1))$$
(21)

Now let \$750 be the grams of oxygen that would be in the globe at a pressure of 750 mm of Hg at 0° C and with the Baromatric pressure the same. With Free representing this pressure, we have

$$\frac{r_{1}}{r_{760}} = \frac{s_{1}}{s_{760}} \frac{z_{1}}{z_{760}}$$
(22)

$$g_{760} = g_1 \frac{Z_1}{Z_{760}} \frac{P_{760}}{P_1}$$
 (23)

and substituting for g_1 from equation (21), we have

$$g_{760} = \frac{(g_1 - g_2) \frac{Z_1}{Z_{760}} \frac{P_{760}}{P_1}}{1 - \frac{Z_1}{Z_2} \frac{P_2}{P_1} [1 + \beta (P_2 - P_1)]}$$
(24)

and finally

$$g_{760} = \frac{(g_1 - g_2) P_{760}}{P_1 - \frac{Z_1}{Z_2} P_2 [1 + \beta (P_2 - P_1)]} \frac{Z_1}{Z_{760}}$$
(25)

Equation (25) allows the mass of oxygen, that would fill Jolly's globe at a pressure of 760 mm Hg at 0° C, to be calculated.

Jolly assumed all of the compressibility factors were equal to one. For making the compressibility correction, I have assumed the compressibility factor, at 0° C to be given by

$$Z = 1 - 0.000965 \frac{P_{mm}}{760}$$
(26)

With the pressure in mm of Hg at 0° C, β is given by

$$\beta = \frac{0.0001101}{760} = 1.45 \times 10^{-7} (\text{mm Hg})^{-1}$$

$$E_{260} = B_{1} \cdot \frac{B_{1}}{2_{700}} \frac{P_{760}}{P_{1}}$$
 (23)

and submittuing for g, from equation (21), we have

$$\frac{2}{2} \sum_{k=1}^{2} \frac{2}{2} \sum_{k=1}^{2} \frac{2}$$

and finally

Equation (23) allows the mass of oxygen, that would fill Jolly's globe at a pressure of 760 am Hg at 0° C, to be calculated. Jolly assumed all of the compressibility factors were equal to one. For making the compressibility correction, I have assumed the compressibility factor, at 0° C to be siven by

With the pressure in um of Hg at 0° C, 8 is given by

The details of the calculations of g760 are summarized in

table 5.

TABI			of oxygen needed 760 mm of Hg at 1	
	P ₁	^g 1 - ^g 2	z ₁ /z ₇₆₀	^g 760
I	714.45	1.356038	1.0000579	1.4426165
II	711.30	1.350156	1.0000619	1.4427259
III	715.02	1.357140	1.0000572	1.4426369
IV	720.42	1.367463	1.0000503	1.4427042
V	722.02	1.370540	1.0000482	1.4427432
VI	706.93	1.341903	1.0000675	1.4427793
VII	693.79	1.316828	1.0000842	<u>1.4426590</u>
			Mean	1.4426950g

The mean for g_{760} given by Jolly is 1.442545 which means my calculated value is higher by a factor 1.00010. This is principally due to the neglect, by Jolly, of the compressibility factor, Z/Z_{760} , and the contraction of the globe.

Using a value of 1.0094221 liters for the volume of Jolly's globe, the values of the density of oxygen at 0° C and under a pressure of 760 mm Hg at 0° C and local gravity were calculated. These values are given in table 6.

TABLE 6 Density of oxygen at 0° (C, 760 mm of Hg, local gravity
	p, g/1
I	1.4291509
II	1.4292593
The change III from a latter	1.4291711
IV	1.4292378
V	1.4292764
VI	1.4293122
VII	1.4291930
Mean	1.429229 + 22

The details of the calculations of gain are summarized in

table 5.

	* - 81 - 82		
			V
			,
		x.	

The mean for g_{760} given by Jully is 1.442545 which means my calculated value is higher by a factor 1.00010. This is princtpally due to the neglect, by Jully, of the compressibility factor, $2/2_{760}$, and the contraction of the globe.

Using a value of 1.0094221 litters for the volume of Joliy's globe, the values of the density of oxygen at 0° C and under a pressure of 760 am lig at 0° C and local gravity were calculated. These values are given in table 5.

	I II III IV V VI VII	

20

The plus or minus is the standard deviation of the mean. REDUCTION OF THE DENSITY OF OXYGEN TO GRAVITY OF 980.616 CM/SEC²

Ph. v. Jolly gives for his laboratory in Munich,

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latitude = 48^{\circ} 8'
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elevation = 515 meters
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Woollard and Rose (16)

(16) Woollard, George P. and John C. Rose

International Gravity Measurements. Published by Society of Exploration Geophysicists, October 1963,518pp., Composed and Printed by George Banta Company, Inc. Menasha, Wisconsin, p. 514.

give for the acceleration of gravity, at Munich, in the Potsdam system for the Residenz station

 $g = 980.7384 \text{ cm/sec}^2$

with

latitude =
$$48^{\circ} 8.5'N$$

longitude = $11^{\circ} 34.9' E$
elevation = 510 meters

The change in g from a latitude of 48° 8.5' to 48° 8' is

The plus or minus is the standard deviation of the mean-REDUCTION OF THE DENSITY OF OXYGEN TO GRAVITY OF 980.515 CM/SEC² Ph. v. Joliv gives for his isboratory in Numich,

> latitude - AS⁶E' . elevation = 515 meters

> > Woollard and Rose (16)

(16) Wooliard, Gaorga P. and John C. Rose International Gravity Measurements. Fublished by Society of Exploration Geophysicists, October 1963, 518pp., Composed and Frinted by George Banta Company, Inc. Menasha, Wisconsin, o. 514.

give for the acceleration of gravity, at Munich, in the Potsdam system for the Resident station

e = 980.7384 cm/sec"

WEED

latitude = 48° 8.5'N longitude = 11° 34.9' E

The change in a from a latitude of 48 6.5' to 48 8' La

2.2

given by Lambert and Darling's tables (17)

(17) Lambert, W. D., and F. W. Darling Tables for Theoretical Gravity According to the New International Formula, Bulletin Geodesique Organe de la Section de Geodesie, No. 32, 1931, pp. 327-340.

as -0.00075.

The change in g from an elevation of 510 meters to an elevation of 515 meters is given by (18)

(18) International Critical Tables, v. 1, 1926, p. 402, McGraw-Hill Book Company, Inc., New York, 370 Seventh Avenue.

 $-0.0003086 \times 5 = -0.00154.$

Thus for Ph. v. Jolly's laboratory

g = 980.7384 - .00075 - .00154 $g = 980.7361 \text{ cm/sec}^2.$

To correct the values given in table 6, to 760 mm of Hg, with g = 980.616, we must multiply by

 $\frac{980.616}{980.7361} = 0.99987754$

ilifer by almost 100 parts per militon (ppm). This difference is principally due to the fact that Wolse applied a buoyancy given by Lambert and Dariing's tables (17)

(17) Lambert, W. B., and F. W. Darling Tables for Theoretical Gravity According to the New In national Formula, Bulletin Geodesique Organo de la Sec de Geoteste, No. 32, 1931, un. 327-340.

The change in g from an elevation of 510 maters to an elevation of 515 meters is given by (18)

(18) International Critical Tables, v. 1, 1926, p. 402, McGraw-

(111 Book Company, Inc., New York, 370 Seventh Avenue

0.0001086 × 5 = -0.00154.

-

Thus for Ph. v. Jally's Laboratory

s = 980.7384 - .00075 - .00154

= 930,/361 cm/sec".

To correct the values given in table 5, to 760 mm of Hg, with g w 980.515, we must multiply by

<u>980.616</u> = 0.99987734

85

TA		f oxygen at 0° C, 760 mm f ity = 980.616 cm/sec ²	of Hg,
	ρ g/1	p g/l (Moles 1921)	Ratio
I	1.4289759	1.42885	1.000088
II	1.4290843	1.42895	1.000094
III	1.4289961	1.42887	1.000088
IV	1.4290628	1.42893	1.000093
v	1.4291014	1.42898	1.000085
VI	1.4291372	1.42901	1.000089
VII	1.4290180	1.42886	1.000111
Mean	1.429054 <u>+</u> 22	2. of V. Regnault on the 1	

These values are given in table 7.

The third column of table 7 gives the values calculated by Moles (19),

(19) Reference 14, page 103.

decreased by 0.00004, as Moles and Gonseles (20)

(20) Reference 15, page 322, Footnote 2.

indicate should be done.

The fourth column of table 7 gives the ratio of the densities calculated by me to that calculated by Moles. The values differ by almost 100 parts per million (ppm). This difference is principally due to the fact that Moles applied a buoyancy

		C 7 Decaley of	
	010,080 = X		C.
		1/3 2	
		I.4289759 I.4290843 I.4290843 I.4289561 I.4290628 I.4291014 I.4291372 I.4290180	I LI JJT ML V IV JV
		1.422054 ± 22	

The third column of table 7 gives the values calculated by

Moles, (19):

(19) Reference 14, page 103

decreased by 0.00004, as Moles and Econsilan (20)

(20) Reference 15, page 322, Fournote 2.

indicate should be done.

The fourth column of table 7 gives the ratio of the densities calculated by me to that calculated by Moles. The values differ by almost 100 parts per million (ppm). This difference ts principally due to the fact that Moles applied a buoyancy correction to the weights in the determination of the mass of oxygen, but he assumed the weights were of brass with a density of 8.4, while I assumed they were platinum with a density of 21.45. This leads to a difference of 87 ppm.

COMPARISON WITH PREVIOUSLY RECALCULATED VALUES OF THE DENSITY OF OXYGEN

In Internal Report No. 44 (21)

(21) Barieau, Robert E.

Recalculation of the Work of V. Regnault on the Density of Oxygen. Helium Research Center Internal Report No. 44, November 1963.

I recalculated the work of V. Regnault (22)

(22) Regnault, V. Deuxiene Memoire. Sur la Determination de la Densite des gaz, pp. 121-150. Troisieme Memoire. Determination du Poids d air et de la Densite du Mercure, pp. 151-162. Memories de l' Academie Royal des Sciences de l' Institute de France, v. XXI, 1847.

on the density of oxygen. The comparison of the density of

correction to the weights in the determination of the mass of oxygen, but he assumed the weights were of brass with a density of 5.4, while I assumed they were platfrom with a density of 21.45. This leads to a difference of 57 women

COMPARISON WITH EREVIOUSLY RECALCULATED

In Internal Report No. 44 (21)

(21) Bartenu, Robert E.

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Recalculation of the Work of V. Segmanit on the Density of Oxygen. Hellom Research Center Internal Report No. 44, November 1963.

I recalculated the work of V. Regnault (22)

(22) Regnault, V. Devetene Memotre. But is Determination de la Densita des gaz, pp. 121-130. Trotsieme bemoire. Determination du Poids d air et de la Densite de Mercure, pp. 151-162. Memories de l' Academie Royal des Sciences de 11. Tressience de l' Academie Royal des Sciences de

on the denalty of cxygen. The comparison of the density of

oxygen follows:

9

Author	p g/1
Regnault, Paris, 1847	1.429626 <u>+</u> 22
Jolly, Munich, 1879	1.429054 <u>+</u> 22

This is the density of oxygen in grams per liter, at 0° C and a pressure of 1 atmosphere, where 1 atmosphere is 760 mm of Hg at 0° C in a gravitational field of 980.616 cm/sec² in the Potsdam system.

oxygen follows:

gnault, Paris, 1

This is the density of oxygen in grams per liter, at 0 0 and a pressure of 1 atmosphere, where 1 atmosphere is 780 mm of ag at 0° 0 in a gravitational field of 980.616 cm/sec² in the

Potedam system.

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