A. Vibert Douglas

Student Note Books (iii)

12.

DEEP·SEA·DEPOSITS·

A. V. Douglas.

References.

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Proc. R. S. Edin. Vol. XXXVI. p. 219. 1915-16

2. " " International Reports on Pedology. vol V. (4) p257-1915

3. J.H.H. Pirie : Scottish Nat. Ant. Exped. 1902-4 Deep-sea deposits.
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4. Murray + Renard : Deep-sea deposits. "Challenger" Reports.
NC. 1. 16. (1-7)

5. Pirie. JHH : Deep sea deposits of S. Atlantic Ocean + Weddell Sea.
Scot. Geog. Mag. Aug. 1905.

6. Sir John Murray : The Sea Floor - Chap. VI of "Science of the Sea" by G. H. Fowler. 1912.

7. J. Joly : Radioactivity + Geology.

8 E. W. Wetherell (Lpool) Track of a Flat Solid falling thro water. Nature Dec 23/22 p. 845.

27.10.22.

J.H.H. Pirie - Ref. # 3.

True "deep sea" deposits - from depths >100 fathoms.

Decantations. 1. mostly under ·02 mm diam & always < ·05 mm. amorphous + clayey matter + mineral ptcls of above dimens. and some siliceous organisms.

2. Siliceous organisms if present predominate also some lighter mineral ptcls of diam betw. ·05 and ·02 mm.

The heavier minerals incl. pract. everything over ·05 mm. remain behind & can be weighed

Calcareous organisms. foraminifera etc.

Globigerina ooze had 24% $CaCO_3$ 40% mineral ptcls
typical " has 70% $CaCO_3$
mostly volcanic in origin. Of the former G. dutertrei & G. pachyderma predominated.

Siliceous organisms - diatoms & radiolaria

Diatom ooze. no $CaCO_3$ or mere trace.

Glacial clay " $CaCO_3$ " " "
" Siliceous " " "
minerals 10 – 80% fine washings, 90–20%

Map of limits of G. + D. ooze bands + discussion of currents, ice pack limits etc. + the marine glacial deposit beds

Summary table gives Depth colour. % $CaCO_3$ % Siliceous organ. % Mineral ptcls + mean diam. % fine washings.

29/10/22.
Cavendish Lab.

"Quest" Deep-sea Deposits.

#1. 20.1.22. Zavdowski S. Sandwich.
18 to 20 fathoms ("not really deep-sea" - ie < 100 fathoms)
terrigineous - coarse - dark grey & black
with occasional white or bricky grains.

#2. 7.2.22. Lat. 67°40'S. Long. 17°.0 E.
2356 fathoms.
light coloured brownish grey ooze. feels soapy
with fine grains to finger

#3. 10.2.22 Lat 67°48'S Long 16°01' E.
2163 fathoms
*granite pebble - retained in Sedgwick.

#4. 12.2.22 Lat 69°8'S. Long. 17°4' E.
1089 fathoms
light coloured brownish grey ooze. feels soapy
& very fine grained - like #2.

#5 14.2.22 Lat. 68°29'S Long. 16°03 E 1925 fathoms
*pelagic mud - only sufficient for 2 slides
~~granite pebble~~ - retained in Sedgwick.

#6 16.2.22 Lat. 66°52'S Long. 14°27' E.
2341 fathoms.
light brownish grey ooze like #2. & #4.

snappers did not act - see if finest is washed out.

31/10/22

#7. 3.3.22 Lat. 65° 43' S Long. 16° 25' W

2766 fathoms. very small sample.

In feeling & colour like #2 #4 #6

#8. 9.3.22. Lat. 66° 07' S Long 38° 11' W.

2622 fathoms.

Very similar to #2 #4 #6 #7.

#9. 12.3.22 Lat 64° 38' S Long 45° 0' W.

2446 fathoms

light grey colour. small sample very dry & brittle.

#10. 13.3.22. Lat 64° 29' S. Long. 45° 43' W.

2331 fathoms

darker & less dry than #9 small sample.

#11. 10.2.22. Lat. 68° 03' S. Long 16° 06' E.

2163 fathoms <u>very</u> small mud sample

#12. 1.3.22. Lat 65° 22' S. Long. 10° 17' W.

2762 fathoms.

light coloured. <u>very</u> small sample.

1.11.22.

#13. 18.3.22 Lat. 63° 49 S Long. 44° 39' W.

1758 fathoms. 3 bottles of chips & 4 loose pieces ?

#14. 3.6.22 Lat 39° 13(?) S. Long. 10° 28' W.

1880 fathoms 58 mi N. of Gough Island.

whitish grey not brownish muddy. Globigerina ooze ?

#15. 6.6.22 Lat. 35° 40' S Long 5° 01' W.

1942 fathoms Globigerina ooze ?

light grey - quite dry - outer layers deeply rusted by contact with tin cylinder.

#16. 6.6.22 Lat. 35° 41.5' S Long. 5° 10' W.

1989 fathoms Globigerina ooze.

Whitish grey - very limey & hard to get uncaked into suspension. deeply rusted.

The rust appears to have penetrated inwards 0.5 cm. on curved surfaces so that a section shows a ring of deep rusty discolouration in curves as though parts of ellipse or oval - the centre being less & less discoloured.

section of ooze plug.

.... lines of discolouring

Dredgings:

1. Terrigenous material from off coast of S. Georgia - approaching Lookout Harbour. 27.3.22. Tallow removed by G.H.W. by simmering with Sodium bicarbonate. Dark pebbles & grains with occasional white & green particles.

2. Terrigenous material taken at approach to Elephant Island. Very much imbedded in tallow - treated as above. Considerable coarse & fine black pebbles & grains with whitish quartz streaks & occasional light coloured particles or greenish bits.

3. 9.5.22. Terrigenous deposit from Royal Bay off Gold Harbour. large dark grey smooth pebbles with 2 irregular white quartz pebbles.

4. Very slow in settling. Water remains opalescent after 2 days, where water above #2 #6 #7 #8 has cleared in ½ day. #9 fairly clear #10 rather muddy opalescent #14 #15 #16 clear rapidly ½ day.

1.11.22. Borrowed set of balance weights:- {Oertling. G. 49. from Mr Crowe. 500 gms, 200, 100, 100, 50, 20, 10, 10 5, 2, 1 1 and 0.5, ·2 ·1 ·1 ·05 ·01, ·01 ·01

2-11.22. Borrowed an Oertling Long Arm Balance with one rider from Dr Heycock, Metallurgical Dept. Chem. Lab. Returned it with rider 22nd Feb. 1923.

Zero at +1.0

Made a 2 mg. rider of about 6 cm Cu. wire S.W.G. #47 covered.

The dredgings imbedded in tallow were simmered gently in distilled water with Sodium bicarbonate. The scum taken off & simmered in another dish, successive scums of first being added to second & scums of second washed & stirred to loosen any ptcls still retained which tail was thrown back into dish & finally two dishes put together & simmered with pure distilled water to remove last traces of grease & of $Na\,CO_3$. Two day job.

Tests to be made.

1. Sp. gr.
2. Determination of sizes
3. Rate of Settling in Sea Water
4. Analysis for calcareous, siliceous & mineral percentages
5. *Radioactive properties.

Weight of 1 piece filter paper
·2
·2
·03
·0022
·4322 gms.

Wt. of Major sample of #4
25.5
·2
·04
·004
25.744 gms.

Wt. of Major sample of #14 25.115 gms.

3. 11. 22.

Balance zero.
−·3 +1.2 +·8 +1
0 +·6
−3 +1.2 2)1.4
·7 +1
·7×5 ·8×5
zero +0·80

Sensitivity 10 mg. rider on div. 1. = 1 mg. in pan
−1.5 0 −1.6 −1
−1 6 0 −1 6 −1
0 −2
−1.53 4
−·753 −1.6 −·133
−·75 −·735

1 mg = 1.55 divisions
or 1 scale division = ·65 mg.

2 mg. rider on div. 5 = 1 mg. in pan.
−2.3 +·2 −1.7 −2
−2.0 0 −1.6
−2. 1.65 ·2
−2.1 +·1 −·9 −·85
−1.0
−·92

1 mg = 1.72 div.
or 1 scale div. = ·58 mg.

10 mg rider on s.d. 1 (repeated)
−2.1 +·4 −1.5 0
1 mg = 1.61 div. 2.0 ·4 −1.8
or 1 scale div = ·62 mg. 2 ·3 ·80
2 ·2
2·2 +
·83

Av. ·63 mg
or 0.6 mg

Wt. of empty dry pycnometer

-3.8 +4.0
-3.6 +3.8
+3.6
-3.7 +3.8
+.05
zero .8 diff. .75 s.d.
= .0475 mg excess.

-0.5+3.0
+2.8
+1.2

Bottle Wt. 18.4555 ~~gr~~ grams.

Temp of distilled water 12.2 °C.

-7.0 +5.4
-7.1 +2.0
1.6
11 18
.35
.8
.45
.3 mg excess

Wt. of bottle + H_2O 68.45 - .01 + .0045 - .0003

68.4442 gms.

∴ Wt. of water W = 49.9887 gms.

Said to contain 50 gms at 60°F.

#14 Glob. ooze 1800 fathoms.

-2

-1.3+2.3
2.1
.45
.80
.35 s.d. = .2 mg. excess.

Wt. of sample taken.

3.77 approx. gms.

Note all the moisture cannot be out of the lump as the change in weight was most evident during weighing the rider being moved from s.d. 9.5 to 1 & then taken off as the pointer moved towards the sample.

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temp of water 13 °C

6.11.22 temp. 10.2 °C. Zero at. +0.5

Wt of Bottle + Sample #14 + H_2O = 69.7496 gms.
18.4555

Wt. of Sample #14 + H_2O = 51.2941 gms.

Wt of Sample #14 after evaporation. 2.7064 gms.

Wt. of evaporation dish. empty. 43.93175
-.00015
43.9316 gms.

8.11.22

Wt. of dish + Sample #14 46.6380 gms.

Wt. of water displaced = 49.9887 + 2.7064 - 51.2941 = 1.4010

$$\text{Sp. gr} = \frac{\text{weight of substance} \times \text{sp. gr. water at } t°}{\text{weight of vol. of water displaced}}.$$

$$\text{Sp gr Sample \#14} = \frac{2.7064}{1.401} = 1.93$$

6.11.22

#15 Glob. ooze 1942 fathoms.

Wt. of major sample. approx. 17.91 gms.

Wt. of sample taken for Sp.gr test → 3.882 gms.
filterpaper .439
3.443 gms.

Wt. of bottle + sample #15 + H_2O. 69.9128 gms.
18 4555
Wt. of Sample #15 + H_2O 51.4573 gms.

Wt. of evaporating dish no. 2. empty 52.3155
Wt. of " dish #2 + sample #15 55.1775
Wt. of sample after evaporation 2.8620
Wt. of water displaced 2.3934

$$\text{Sp.gr.} = \frac{2.8620}{1.3934} = \cancel{1.20}\ 2.05$$

#16 Glob. ooze 1989 fathoms

Wt. of major sample. approx 10.4840 gms.

Wt of sample taken for sp.gr test 3.7600
.4390
3.321 gms.

Wt of bottle + sample #16 + H_2O. 70.2807 gms.
temp. 13.2°C 18. 4555
Wt. of sample #16 + H_2O 51.8252
Evap. dish #2 52.2980 gms.
8.11.22. Wt. of bottle + sample #16 + H_2O 70.2055 gms. (air bubble
" " " bubble replaced " 70.2770 gms. ←
Dish + sample 55.2370 gms.
∴ Sample 2.939 gms

$$\therefore \text{Sp.gr} = \frac{2.939}{1.106} = \cancel{2.65}$$

Later weighing gives ~~2.67~~
See Summary p.21.

7.11.22.

Note. The difficulty in expelling all the air bubbles attached to the suspensoid is very considerable & it is uncertain whether it is actually accomplished. In the case of #14 #15 enough care was not taken. In # the pycnometer was well shaken & left overnight when a considerable bubble was found to have accumulated by morning.

Try carbon tetrachloride.

Note. CCl_4 may dissolve some of the constituents. It is a colourless liquid B.p. 78°. Sp.gr. 2.86.

#2 Mud (siliceous) 2356 fathoms.

Wt. of bottle + Sample #2 + H_2O 69.3775 gms.

Wt. of evap. dish no. 1. 43.9306 gms.

Wt. of dish 1 + sample #2 45.4580 gms

Sample #2 1.5274 gms

$$\therefore \text{Sp.gr.} = \frac{1.5274}{\cancel{68.3645 + 1.5274 - 69.3775}} = \cancel{\frac{1.5274}{.5144}}$$

$$68.4256 + 1.5274 - 69.3775 = \frac{1.5274}{.5754} = \cancel{2.65}$$

Corrected value 2.53 See Summary p.21.

9.11.22

#4 Pelagic Mud 1089 fath (furthest south)

Wt of bottle + Sample #4 + H_2O 72.4238 gms.

Wt of evap. dish no 3. 53.5435 gms.

Reweighed pycnometer full of H_2O 68.4106 gms.

10/11/22 " " " " 68.3845

" " " " air removed – 68.4255 ←

evap dish 3 & sample #4 59.9050 gms.

Wt. of sample #4 6.3615 gms.

$Sp\,gr. = \frac{6.3615}{2.3632} = \cancel{2.69}$ See corrected value p.21.

10/11/22

#6 Pelagic Mud 2341 fathoms

Wt. of bottle + Sample #6 + H_2O 71.2805 gms.

Wt. of evap dish. 43.9306 gms.

Wt. of " dish + sample #6 48.375 gms.

" " Sample #6 4.4444 gms.

$Sp\,gr. = \frac{4.4444}{1.5894} = \cancel{2.80}$ Corrected 2.75

See Summary p 21

7/11/22

Ref. #6. Murray.

Animals & plants which float in the Sea whether at surface or in deep water are called Plankton.

Of the single cell animals (Protozoa) those wh. form a skeleton of lime are called Foraminifera; those which either form no skeleton or form it of something other than lime (eg. silica) are the Radiolaria.

globigerina is one genus of Foraminifera

Foraminifera, calcareous Algae, Corals, Alcyonarian & Tunicate spicules, worm tubes, Ostracod & Cirriped shells, Echinoid spines, & Molluscs, Polyzoa shells & bones of fishes, whales &c. are composed of Calcium Carbonate.

Diatoms, Radiolarians & Sponge spicules are Siliceous (flinty).

Deposits are of 5 kinds (1) Organic as above.

(2) Terrigeneous - Brought down by rivers, worn from coasts, carried by icebergs

(3) Volcanic materials - dust - pumice -

(4) Planetesimal dust - cosmic spherules of iron + nickel + chondrites with lamellar structure.

(5) Secondary or chemical products - Clayey matter arising from decomposition of pumice, felspars + other minerals; manganese nodules; palagonite + zeolitic materials; greensand glauconite; phosphate concretions, BaSO$_4$ nodules, iron + calcareous concretions &c.

Pelagic deposits (1) Red clay, amorphous, very few ~~deposit~~ remains of calcareous or siliceous organisms. (2) Radiolarian ooze - chiefly composed of R. remains. (3) Diatom ooze chiefly composed of D. remains.

(4) Globigerina ooze. chiefly calcareous remains of Foraminifer with genus G. predominant. depths less than 2500 fathoms. generally 1500 - 2000

(5) Pteropod ooze chiefly calcareous remains but pelagic Molluscs (Pteropod + Heteropod) predominant depths 800 - 1000 fathoms generally as Mollusc shells are more easily dissolved by sea-water.

Terrigineous Deposits Blue Mud. Red Mud Green Mud. Volcanic Mud. Coral Mud.

Examination by J Joly for radium content showed Red Clays & Radiolarian oozes contain much more radium than the Globigerina oozes or terrigineous deposits. in fact radium content is gtst where rate of deposition is believed least. Hence hypothesis that Cosmic dust has high Radium content. (Contradicted on p. 23 by Joly)

8.11.22.

#7 Pelagic Mud 2766 fathoms

Wt. of bottle + sample #7 + H_2O 68.6180 gms.

Wt. of evap. dish no 2. 52. ~~3017~~ ~~3017~~ ~~2917~~ .2524 .. T. .2595

Wt .. .. + Sample #7 52.5430 gms.

Sample 0. ~~2513~~ 3100 gms.

$$\text{Sp gr} = \frac{\overset{.299}{0.3100}}{\underset{115}{1175}} = \cancel{2.64} \quad 2.51$$

Corrected see p. 21.

#8 Pelagic Mud 2622 fathoms.

Wt of bottle + sample #8 + H_2O 70.0137

Wt. of evap dish 3. 53.4653 gms.

Wt .. .. .. + sample 8 55.9220 ..

Wt of ~~sample #8~~ dish #3 hot. 53.4220 ..

Wt of sample #8 2.500

$$\text{Sp gr} = \frac{2.500}{9.118} = 2.74$$

See p. 21 for corrected value 2.69.

14/11/22.

Type of sample ascertained from

Chart 1. Deep-sea Deposits. Sir J. Murray. Chall. Reports.

#1. Terrigenous. Zawodowski Is.

#2 67°40'S 17°0'E 2356 fath. Diatom ooze
Terrigenous (Blue Muds) just south.

#3. 67°48'S 17°4'E 2163 fath. Diatom ooze.

#4. 69°8'S 17°4'E 1089 fath This is actually very similar to 2 + 3 though more opalescent when settling as referred to previously but lies within Murrays belt of terrigenous deposit no Diatom being shown S. of lat 68 at this long.

#5 68°29'S. 16°03'E 1925 fath. Same remarks as #4

#6 66°52'S. 14°27'E 2341 fath. Diatom ooze.

#7 65°43'S 16°25'W 2766 fath.

#8 66°07'S. 38°11'W. 2622 fath. In Terrigenous belt of Murrays chart. actually like #6 + #7 apparently ∴ Diatom.

#9 64° 38' S. 45° 0 W 2446 fath within Murrays Terrigenous belt which here extends to lat 61-62. actually very like Diatoms above

#10 2331 fath. same remarks as for #9

#11 68° 03' S. 16° 06' E. 2163 fath

#12 65° 22' S. 10° 17' W. 2762 fath

#13 63° 49' 44° 39' W 1758 fath Terrigenous

#14 39° 13' S. 10° 28' W. 1880 fath. Glob. ooze.
#15 35° 40' S 5° 01' W 1942 fath. Glob. ooze.
#16 35° 41' S 5° 10' W. 1989 fath. Glob. ooze
very near a small Pteropod ooze area.

16/11/22.

Discovered that the evaporating dish increases wt. after having been heated & at a rate indicating that the increase previously ascribed to the deliquescence of the ooze is due to dish entirely.

Reweighed dish #2 52.254 gms within 5 min of taking off hot pan to 52.2595 gms" 2 hours ....

Similarly dish #1 43.9160 gms within 5 min to 43.9290 at 2 hrs.

Similarly dish #3 from 53.422 to 53.465

Correcting Specific Gravities for this error.

# 14.	Spgr.	1.93.	Average for Globigerina 2.14
# 15.		2.05	
# 16		2.44	
# 2		2.53	Average for diatom ooze 2.63
# 4		2.67	
# 6		2.75	
# 7		2.51	
# 8		2.69	

Ref. #7. Joly.

p. 58. Mean Sp. gr. of deep sea deposits is 2.5

p. 49 Radium content of Murrays deposits.
as determined by Joly. Phil Mag. July 1908 p. 190.

Glob. ooze.	Lat. 21° 13' S	Long 14° 2' W.	1990 fath.	6.7×10^{-12}.
Red clay	" 24° 20 N	" 24° 28 W.	2740 fath.	15.4 10^{-12}
" "	Pacific		2350 fath	52.6 10^{-12}.
Radiolarian	"		2600 fath.	22 to 50 10^{-12}.

$$\% \text{Ra} \propto \frac{1}{\% \text{CaCO}_3}$$

Cosmic dust is <u>not</u> the source of high values showing (one sample only sent by Murray 1.1 grms & mag. ptcls removed) 0.6 10^{-12}

p. 125 Radioactivity of the sediments due to the precipitation of Ur. all over the ocean (originally comes from the denudation of igneous rocks – via sedimentary sometimes) & the dilution of this precipitate with other precipitates gives the varying Ra contents of the fast & slow accumulating deposits.

3-5 10^{-12} for terrigenous deposits.
6-8 " glob ooze
30-50 " red clays & radiolarian oozes.

Joly Phil Mag. 1908 July. p. 190.

Method A. Fuse substance in a platinum crucible with mixed carbonates of Na & K. The melt is leached in hot water. Filter & dose the filtrate as the alkaline solⁿ. Treat the residue with HCl & close as the acid solⁿ. If latter develops a precipitate filter & refuse with the carbonates & treat as before

Method B applicable to Glob. ooze where % of insoluble substance is small & known to have low Ra content. Boil in HCl & close the filtered solution.

Methods C.D.E. for special cases.

19/11/22

Found that it will not be possible to obtain the range of resistances & amps to give an electrical compensation over the whole range of sample accumulation.

20/11/22.

Fitted up a burrette with fine tube entering balance case so that drops of H_2O (or other liquid if preferred) fall into small beaker on counterpan.

35 drops = 1 cc.

50 drops	counterbalance	1.6 gms –	1 d	=	·032 gms.
31					
81 "	overbalanced	2.6 "			
59					
140 "	counterbalanced	4.6 "	1 d	=	·0328 "
150		5			
290 "	" "	9.6 "	1 d	=	·0331

22/11/22. Trial Test with crushed ore _ S.R. Exped. C.138.

LH Pan (immersed in distilled H_2O counterbalanced by beaker + 0.67 gms on RH Pan + solder wt. suspended on division 9 of LH balance arm.

Evap. dish 2 | 2.3

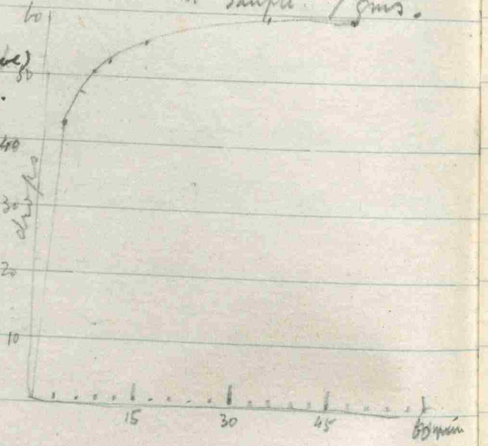
" " 2 + Sample C.138 | 9.3 | Sample 7 gms.

" Sample 7 gms.

0 min 10^{26} am.

3 min 43 drops (excessive)

	1	11^{23} am	25	23/11/22.
4	1½	5	35	
	2	48	42	
5	2½	1	45	
	3	49	47	
5½	3¾	1	49	
6	5	50 1	50	
	5½	51 1	51	
7	6	52 1	52	
8	7	53 1	53	
10½	8	54 1	54	
12	10	55 1	55	
16	12	56 1	56	
	15		57	
22	21	57 1	58	
32	29	58 1	59	
49	42	59 1	60	
67	22^h	60 3	75	
$6^h 20$ am		63		
22 hrs.		6 69		
↑		↑		



Note. Ref II 1. p. 228 et sq.
Why does Svenôden make his calculations with h instead of $\frac{h}{2}$ since Average depth of fall is certainly $\frac{1}{2}h$. ?

Ans. See full Math showing that h comes in only as the limiting depth when all ptcls of a given radius have settled.

24.11.22.

15 drops added in am. after a lapse of about 20 hours seems unduly high. To test for evaporation loss 1.7 gms were put on LH pan + water dropped into RH beaker (approx 75 drops covering bottom) until a balance was obtained.

	10^{am}		temp = 15°C.
	12^{am}	1 drop added.	
	2 pm	1 " "	
	4	almost overbalancing	
	5 pm.	1 drop.	
25/11/22	9 am	6 "	temp = 10°C.
	10^{45}	1 "	
	12^{30}	1	temp = 8°C.
27/11/22.	10 am	15 "	

This seems to indicate that for temp 15°C. the loss in wt. by evaporation is approx 0.5 drop per hour — or over the critical part of the curve of 22.11.22 0.2 drop in 30 min. which is on 58 drops an error of 0.43%.

For temp 10°C. the loss is approx 0.37 drops per hour.

For temp 8°C (not known what average was for Sunday) the loss was approx. over 46 hours 15 drops = 0.33 drops/hr.

28/11/22	10^{30} am	3 drops.	temp 10°C
	2^{30} pm	1 "	temp 12°C
29/11/22	9^{00} am	4 "	" 12°C.

27/11/22. Set up an electroscope of lead 10 cm cube. with a thin Al. face downwards. charged with stick of red sealing wax on hair.

28/11/22 Nat. leak. 65 — 45 13' 38" 1.47 div/min

This is excessive. Rewaxed new base.

Nat leak. 55-40 10' 56" 1.37 div/min.
38-18 14' 42" 1.36 div/min

Small piece of Blömstrandite under elsp.

81-72 6' app. 1.50 div/min.
69-59 5' 26". 1.84 " "
Leak. 57 - 49 5' 36" 1.43.
Blömstrandite 47 - 36 6' 47" 1.62
Leak 34 - 25 6' 12" 1.45
Blomstrandite 59 - 42 6' 22" 2.67 whitish side up.
Pm Leak. 85 - 71 8' 52" 1.57
Blomstrandite 69 - 59 5' 36" 1.79
" 52 - 39 5' 55 2.20
55 - 39 8' 18" 1.93

Leak 48-39 6' 25" 1.49 div/min.
#2 60 - 43 10' 53" 1.43 Tray 5 cm below elsp.
powder in brass tray 55-45 7' 12" 1.39 Tray raised to 1 cm from base of elsp.

29/11/22

Leak 73-61 8' 44" 1.38
#15 58-44 9' 6" 1.54
Leak. 41-34 4' 40 1.50
#15. 68-54 5' 23" 2.60 ?
Leak 46-38 5' 48' 1.38
#15 34-27 4 54 1.43

Very unsatisfactory.

<u>Electroscope in window of Pt.II Lab.</u>

Leak. 65-61 5' 12"
#15 59-51 10' 5"
Leak 50-46 5' 7"
#2 42-36 7' 7"
Leak 35-31 5' 25"

Contd p. 42.

29/11/22

Accumulation Curve for # 2.

Balance adjusted with ·674 gms + 1 drop & beaker to R.H. pan.

$10^{\underline{06}}$ am.

hr min sec.	drops		%
0 1 40	100	100	
2 10	4	104	
30	3	107	
52	2	109	
3 12	2	111	
35	2	113	
4 0	2	115	
4 33	2	117	
5 6	2	119	
52	2	121	
6 45	1	122	
7 6	1	123	
42	1	124	
8 10	1	125	
48	1	126	
9 30	1	127	
10 20	1	128	
11 12	1	129	
12 10	1	130	*
13 15	1	131	
14 15	1	132	
15 20	1	133	
16 35	1	134	
17 53	1	135	
19 8	1	136	
20 30	1	137	
	1	138	
23 25	1	139	
25 3	1	140	

h. m s	drops.		temp 14.6 %	
0 26 40	1	141		
28 30	1	142		
30 25	1	143		
32 20	1	144		
37	1	145		
	1	146		
	1	147		
	1	148		
45 40	1	149		
49 10	1	150		
	1	151		
56 40	1	152		
1 1 40	1	153		
7 15	1	154		
13 45	1	155		temp 14.6
	2	157		
4 24 0	7	164		temp 15.2
evap^n	-2	162		
6 5 0	1	163		
			temp 13.8*	
23 18 0	9	167	·· 13.8	
evap correction	-5			
Residue	3			
		170		

Drew off water with syphon but disturbed deposit.

30/11/22.

Repeating $Acc^{\underline{en}}$ Curve for # 2.

$12^{\underline{26}}$

m. s.		
	50	
1 0	1	51
15	14	65
15	?25	90
55	10	100
2 20	3	103
35	3	106
3 .	2	108
20	4	112
52	2	114
4 15	1	115
28	1	16
43	1	117
5 .	1	118
18	1	19
40	1	120
6 2	1	121
26	1	122
44	1	123
7 24	1	124
8 .	1	125
35	1	126
9 15	1	127
10 .	1	128
50	2	130
12 25	1	131
14	1	
40	1	133
15 50	1	134
17	1	135
18 10	1	136
	1	137
20 45	1	138.
22 15	1	139
	20	159

h. m. s.			
5 34 0	15	174	excessive
evap.	-2	172	
23. 0. 0	0		temp 13.2
evap	-4	168	
Residue	3		
		171	

Drew off water by syphon.

$h = 4.5$ inch.

Proportion of water drawn off $= \frac{4.1}{4.5}$

Area of pan to area of cross. section of flask $= \frac{\pi(2.5)^2}{\pi(2.875)^2} = ·757$

Wt of residue $= 52.434 - 52.225$

$= 0.209$ gms.

$=$

Equivalent wt of residue if on pan immersed in water $=$

Wt in air $(1 - \frac{1}{\rho})$ where ρ = density

$= 0.209(1 - \frac{1}{2.5}) = 0.1254$ gms.

$=$ 3.8 drops

∴ Residue which wd. have settled on pan

$= \frac{45}{41} \times ·757 \times 3.8 = 3.16$ drops.

11/12/22

Calculation of r.

time 0 - 15' temp app. 13.8 $\therefore \eta = .0118$

$$C = \frac{2}{9} g \frac{\sigma_1 - \sigma_2}{\eta}$$

$$= \frac{2}{9} \times 981 \times \frac{2.53 - 1}{0118} = 28300$$

$$r = \sqrt{\frac{h}{ct}} = \sqrt{\frac{10}{283\cancel{00}t}} = .0188\sqrt{\frac{1}{t}}$$

$$F(r) = -\frac{2t}{r}\frac{dz}{dx}\frac{dP(t)}{dt}. \quad ①$$

$$= \frac{-2t}{.0188\sqrt{\frac{1}{t}}}\frac{dz}{dx}\frac{dP(t)}{dt}$$

$$= -\frac{t^{3/2}}{.0094}\frac{dz}{dx}\frac{dP(t)}{dt}. \quad ②$$

As r has to be evaluated in any case ① is preferable to ② for F(r)

9/1/23

Results shows when plotted a U-shaped distribution but readings very irregular. Error is probably in recording t as instant when drop entered glass instead of instant when pointer began to move. The lag in getting drop detached is not constant hence the t as recorded is meaningless.

Curve points to the following conclusions

38.2% of the ooze is composed of ptcls $r > 20\mu$

2. % " " " " " " $r < 0.69\mu$

there are large proportions having r within the limits $18\mu \pm 2\mu$ and $2.1\mu \pm 1.5\mu$ and comparatively few particles or rather a low proportion consists of ptcls of the intermediate values of r namely $10\mu \pm 5\mu$ with the minimum at 12.2μ.

Table showing Effect of Temp on Viscosity of Water
copied from Int. Reports on Pedology (Ref. 2)

Temp.	η	Typical value of constant C.
10 °C	0.01307	27890
11	·01296	28354
12	·01235	30007
13	·01202	308
14	·01171	316
15	·01140	325
16	·01110	334
17	·01082	343
18	·01055	351
19	·01029	360
20	·01004	36900

Dec. 1st 1922.

Accumln. Curve for #14.

h. m. s.	drops.	Total	%
10 58 am			
	25		
45	33		
0 1 6	10		
36	14		
52	5		
2 9	3		
24	2		
40	2		
5 30	2.		
~~12 08~~ am.			
12 11 am			
	35		
50	5		
1 15	6?		
2	6		
0 45	11	46	
1. 0	6	52	
18	4	56	
36	4	60	
48	4	64	
2 3	3	67	
15	3	70	

	h. m. s.	drops.	Total	
temp 15.4	0 2 33	6	76	
	54	3	79	
	3 10	3	82	
	30	2	84	
	50	3	87	
	4 10	3	90	
	35	2	92	
	55	2	94	
	5 25	1	95	
	54	2	97	
	7 .	1	98	
	48	1	99	
	8 52	1	100	
	10 30	1	101	
temp 16	12 57	1	102	
	17 6	1	103	
	24. 0	1	104	
	33 45	1	105	
	2 11 .	2	107	
	3 50 .	1	108	temp 15.2
	21. . .	7		13.4
	Evap	−5	110	
	22	1	111	
	24			
	Residue	4	115	

h = 3.5 inch.

Water syphoned off $\frac{3.25}{3.50}$

9/12/22.

$1.5 \quad \frac{\cdot 7}{1}$

-1.5785

$65 = -\cdot 37$

Wt of Evapdish 2 + Residue #14 52.5645 gms.

wt. of dish. 52.2155

Residue ·349 gms.

Equiv. wt in water $= \cdot 349(1-\frac{1}{1\cdot 9}) = \cdot 349 \times \cdot 474$

$= \cdot 162$ gms $= \frac{\cdot 162}{\cdot 0331}$ drops $= 4.9$ drops.

Proportion wh. wd. have settled on pan

$\frac{3.50}{3.25} \times \cdot 757 \times 4.9 = 4$ drops.

Accumulation Curve Data for 14

re obtained as on p. 48 10/1/23. ~~5/12/22~~.

Points to be noted in writing up results.

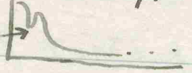
1. Interpret^n of $F(R)$ p. 230 or p. 231 former seems correct.

(2) S. Oden plots $rF(r)$, $\log_e r$. whereas I am plotting $F(r)$, r.

(3) Undue prop^n of largest sizes falling within first 20" or so makes grading of ptcls whose $r > 40\,\mu$ very difficult.

(4) If unequal increments of r are plotted replace $F(r)$ by $F(r)/_{r_n - r_{n-1}}$ see notes p. 57. explaining away this idea.

(5) Ref. **2** shows that S. Oden does not obtain $\frac{dz}{dx}$ by 2nd diffs as I am doing but plots (z, x) + takes smooth values i.e. draws smooth curve + gets tan from it.
He plots $F(r)$ ag. r in this paper. + note that he joins up $r = 0$ to his first reading which is ~~1.6~~ ~~2.2~~ 1.2 μ for ("Boden Kosta. 11").

see p. 298 & tables pp 295-297. Note also that he gets the kink  . . . . for small values of r which I have got in every case ("Boden 117 Kosta" kink minimum at 2μ.)

I should plot my values of $F(r)$ against r so that the pt was over the mid value of the interval $r_n - r_{n-1}$ not over r_n. This means only a slight shift of the curve to the left. Soden does his auxiliary curve this way but scale of final curve is too small to tell definitely.

Sample of 10 gms of av. $\rho = 2.6$, av. $r = 20\mu$

The no. of ptcles. composing the sample is given by $N(r) = F(r) \big/ \frac{4}{3}\pi r^3 \sigma$

$$= 10 \big/ \tfrac{4}{3}\pi\ 8\ 10^3\ 10^{-12}\ 2.6 = \frac{1}{8.7\ 10^{-9}}$$

$$= 1.15 \times 10^8$$

This is an underestimate since 20μ is the average by mass not by number.

2/12/22.
Contd. from p. 29.

Leak	60-52	8'48"
#2	50-44	7'30"
Leak	41-35	7'45"
#15	60-52	9'46"
Leak	50-44	7'30"
#14	41-35	7'46

Dec. ~~4~~ 5th

Accumuln Curve for # 4.

temp 15°C.

~~11 45~~
11 27 ↗ 30 ~~25~~
0.3

1 30	60	90
45	4	94
2 5	3	97
15	3	100
26	2	102
51	2	104
3 10	2	106
30	2	108
55	2	110
4 23	1	111
37	1	112
54	1	113
5 15	1	114
51	2	116
6 18	1	117
45	1	118
7 ?	1	119
45	1	120
8 12	1	121
-	1	122
9 15	1	123
50	1	124
10 27	1	125
11 10	1	126
11 ?	1	127
12 30	1	128
13 15	1	129
13 57	1	130
14 40	1	131
15 24	1	132
16 8	1	133
16 55	1	134
17 45	1	135
18 30	1	136
19 24	1	137

0.20.12	1	138
21 5	1	139
21 56	1	140
22 54	1	141
23 48	1	142
24 50	1	143
26 ·	1	144
27 10	1	145
28 30	1	146
30 · Really 29	1	147

5/12/22

Repeating Accum^{n} Curve for #4.

3^{10} pm

	50		
0 50	21	71	50
1 8	10	81	68
25	6	87	85
41	4	91	101
2 2	3	94	122
15	3	97	135
27	3	100	147
52	2	102	172
3 22	3	105	202
52	2	107	232
4 19	1	108	259
34	1	109	274
50	1	110	290
5 10	1	111	310
34	1	112	334
55	1	113	355
6 16	1	114	376
43	1	115	403
7 5	1	116	425
30	1	117	450
8 0	1	118	480
30	1	119	510
55	1	120	535
9 25	1	121	565
54	1	122	594
10 24	1	123	624
52	1	124	652
11 20	1	125	680
54	1	126	714
12 21	1	127	741
50	1	128	770
13 24	1	129	804
~~#~~ 56	1	130	836
14 27	1	131	867
15 2	1	132	902
34	1	133	934

temp
17

16 9	1	134	
43	1	135	
17 21	1	136	1041
18 1	1	137	
43	1	138	
19 24	1	139	1164
20 ?	1	140	
57	1	141	
21 ?	1	142	
22 40	1	143	1360
23 40	1	144	
24 50	1	145	
26 7	1	146	1567
27 40	1	147	
29 22	1	148	
31 22	1	149	1882
34 .	1	150	
37 15	1	151	
40 22	1	152	2422
47 30	1	153	
54 5	1	154	
67 .	1	155	4020
84 . .	1	156	5040
115 .	1	157	6900
18^h 0.0	8	165	
Evap. loss	-4	161	64800
20^h 45 0	1	162	74700
23. app.	1	163	
24 actual	1	164	86400
Evap.	-1	163	
42^h	6	169	151200
Evap.	-4	165	
Residue 5		170	

h = 3.8 inches = 9.65 cm.

Prop^{n} of liquid syphoned off & evap^{d} (majority lost & dish smashed) : $\frac{1.1}{3.8}$

5^{30} pm
Temp 16.8

9 am 6/12/22
temp 13.5

12 am
Temp 14.5

3 pm
temp 15.8
15.4

9 am 7/12/22
temp 11.8

9/12/22.

Wt of evap dish & residue #4 43.4032 gms.

" " " ——— 43.~~5915~~ 923

Residue ~~.4405~~ .109 gms.

Equiv. wt in water $= \frac{.109}{\cancel{.4405}}\left(1-\frac{1}{\rho}\right) = \frac{.109}{\cancel{.4405}}\left(1-\frac{1}{2.67}\right)$

~~=.276 gms = 8.35 drops~~

= .068 gms = 2.06 drops.

Prop^{n} wh. wd. have settled on pan

$= \frac{3.8}{1.1} \times .757 \times 2.06 = 5.38$ drops.

1080
60
64800
3600 × 20 = 72000
2700 } 74700

36
24

72
864

112
36
151200
252
126
1512

Time 0 – 120 min. temp 17. ∴ $\eta = .01082$

$C = \frac{2}{9}\,981\,\frac{2.67-1}{.01082} = 33600$

$r = \sqrt{\frac{h}{Ct}} = \sqrt{\frac{10}{33600}}\,t^{-\frac{1}{2}} = \underline{.0172\sqrt{\frac{1}{t}}}$

Time 18^h " 20^h temp 13.5 / 14.5 } $\eta = .0117$

$C = 31100$ $r = .0179\sqrt{\frac{1}{t}}$

" 24^h temp 15 $\eta = .0114$ $C = 31900$ $r = .0177\sqrt{\frac{1}{t}}$

42^h " 12 $\eta = .01235$ $C = 29400$ $r = .0184\sqrt{\frac{1}{t}}$

17/2/23.

Determination of upper limit of diameters of particles by means of a travelling microscope

(Cav. Lab. Pt. II M.S.) (X18 diams)

Calibration $\frac{1}{16}'' = 7.00 - 6.84$ [illegible] $= 0.16$ 20×0024

6.684 $= 0.156$ ~~.048~~

17×002[illegible]

34

25 v.d. = 24 s.d.

$1\ v.d = \frac{24}{25}\ s.d. = \frac{24}{25} \times \frac{1}{20}$ cm = ·048 cm.

1 s.d. ·05 cm.

∴ 1 v.d is < 1 s.d by ·002 cm.

6.624 − 6.46 = 0.164

6.620 − 6.780 = 0.160

= ·160

$\frac{1}{16}''$ = ·160 cm on travelling scale.

∴ 1 cm on scale = ·991 cm

Pebble in Z.4   6.780 − 6.934   long

looks like a globigerina

= ·154 cm. = 0.15 cm.

7·066 = ·132 = 0.13 cm wide.

black oval   7.066 − 7.054 = ·012 cm

See p. 67.

Repeating #14. Jan. 10th 1923.

× See foot note p. 32. re time t.

	40					
	20					
120	2					
50	1					
29	1					
32	1					
11^26 am				Seconds		
47	50		47			t 11°C
	3	53	60	×		
1.0	3	56	70			
10	2	58	83			
23	2	60	100			
40	2	62	126			
2 6	1	63	142			
22	1	64	161	16		
41	1	65	184	19		
3 4	1	66	205	23		11.3
25	1	67	241	21		
4 1	2	69	295	36		
55	1	70	338	27		
5 38	1	71	385	43		t 11.6
6 25	1	72	443	47		?
7 23	1	73	504	58		
8 24	1	74	565	61		"
9 25	1	75	633	68		
10 33	1	76	704			
11 44	1	77	772			
12 52	1	78	852			
14 12	1	79	928			
15 28	1	80	1092			
	1					
18 12	1	82	1175			
19 35	1	83	1356	1426	? Prob. original in correct.	11.4
23 46	1	84	1452	1512		
25 12	1	85	1540	1600		
26 40	1	86	1642	1702		
27 22	1	87	1738	1798		
28 58	1	88	1848	1908		
30 48	1	89	1960	2020		

	33 40	1	90	2030	2140	
	34 40	1	91	—		
	36 ?	1	92			
39	37 55	1	93	2415	2535	
42	40 15	1	94	2560	2680	
44	42 40	1	95	2728	2848	
47	45 28	1	96	2910	3030	
50	48 30	1	97	3101	3221	t: 11.6°C
53	51 41	1	98	3305	3425	
57	55 5	1	99	—		
	57 55	1	100	3743	3803	Stop watch 2 min slow in the hour. min hand is wrong.
	1h 2m 23	1	101	4032	4092	
	7 12	1	102	—		
	16 ?	1	103	4737	4797	
	18 57	1	104	—		
	2h 55 ?	8	112	—		t = 12.8°C
	3h 6 ?	1	113	12510		t 13°C
	28 30	1	114	—		
	4h 8 ?	1	115	16460		
	34 20	1	116	—		12.6°C
	5h 30 ?	1	117	—		
	21h ?	8				t. 10°C
	Evap.	-5	120	85200		
	23h 40'	1	121			t 10.6
	26h ?	1	122	∞		
	Evap. ∞	-1				
	Residue	2	123	∞		

h = 3.5 in

Propn syphoned off = $\frac{2.3}{3.5}$

Weight of Evap. dish #2 52.185 gms.

" " " + residue 52.311

Residue 0.126 gms.

Equiv. wt. in water $.126 \times (1 - \frac{1}{\rho})$

$= .126(1 - \frac{1}{1.93}) = .126(1 - .518)$

$= .126(.482) = .0607$ gms.

$= \frac{.0607}{.0331}$ drops $= 1.83$ drops.

Residue on pan $= .757 \times \frac{3.5}{2.3} \times 1.83 = 2.12$ drops.

14400
2060

24 × 3600
86400
1200
85200

10800
1680
30

12570

22.1.23 Repeating beginning of curve. for points betw. 0" and 60"

	3.5	
15	25	60
25	18	78
	4	82
46		
55	4	86
1 20	4	90
45	3	93

Cl. 13 11^45 am

15	65	65
33	14	79
45	4	83
1.0	4	87
20	3	90
1 53	3	93
2 27	3	96
	3	99
4 15	2	101
7 26	6	107
	41	148
38 30	1	149
	7	156
2h 35m ?	13	169
	1	170
23h —	23	193

temp 13°C

t = 13.75

sec	10 t	wt.	wt.	smoothed values
	37.5 42.54			
15	15.8	42.7	39.3	36.5
33	34.7	51.8	47.8	45.0
45	47.3	54.5	50.2	48.8
60	63.1	57	52.6	✓
80	84.1	59	54.4	56
113	119	61	56.2	
147	154.7	63	58	
255	268	66.3	61	
446	469	70.3	64.6	
—				
2310	2430	97	90	

$\rho = 1.93$

time 0 - 60 temp 13°C $\eta = \cdot 01202$

$c = \frac{2}{9}\ 981\ \frac{\cdot 93}{\cdot 01202} = 16900$

$r = \sqrt{\frac{h}{ct}} = \sqrt{\frac{10}{16900}}\sqrt{\frac{1}{t}} = \cdot 0243\sqrt{\frac{1}{t}}$

time 60"-240" temp = 11°C $\eta = \cdot 01296$

$c = 15650$ $r = \cdot 0261\sqrt{\frac{1}{t}}$

time about 12000" temp 13°C. η = as above.

Remarks on Distribution graph.

36.6% have effective radii > 41 μ.

2.4% " " " < 0.84 μ.

Of the remaining 61% the major portion have radii within limits 1 μ to 6 μ while the rest are fairly evenly distributed from r = 6 μ to r = 40 μ except for 27 μ to 34 where there are very few.

11/1/23.

Replaced distilled water by parrafin oil.

Balance adjusted with approx. 40 drops in small beaker R.H.S. temp 13. time 4^{10} pm. Thurs. Allowed to stand until Sat. to test for Evaporation loss.

13/1/23 Drops had fallen during absence - Taps not air tight. Rebalanced it 11^{15} am and removed dropper.

15/1/23. At 10 am. 10 drops req^d i.e. $\frac{47}{10}$ = 4.7 hrs per drop evaporated.

Not much improvement on water

Try a small specimen bottle instead of open beaker. Area of water surface will be about $\frac{1}{3}$.

at 3^{00} pm. balanced with app. 30 drops water.

16/1/23 10 am less than 1 drop req^d i.e. not 1 in 19 hrs.

16.1.23.

Globigerina #15 Clock 25.0.

10 50

		40				
1	45	94				
3	0	4				
	30	4				
4	5	4				
	45	4				
6	30	3				
		3				
11	10	80				
1	30	4	124	90	diffs	per drop
2	10	5	129	130		
	38	3	132	158	28	9.3
3	8	3	135	188	38	12.7
	38	3	138	218	38	12.7
4	10	4	142	250	32	8.0
	42	4	146	282	32	8.
5	8	3	149	308	26	8.7
	35	4	153	335	27	6.8
6	16	4	157	376	41	10.2
	57	4	161	417	41	10.
7	50	4	165	470	53	13.2
8	58	4	169	538	68	17
10	28	3	172	628	90	22.5
12	9	3	175	729	101	35.
13	34	2	177	814		
15	29	2	179	929		
18	10	2	181	1090		
22	20	2	183	1340		
28	30	2	185	1710		
39	0	2	187	2340		
62	10	2	189	3740		
83	·	1	190	4980		
?		1	191			
?		2	193			
23^h 0	0	5	197			
evap.		−1				

Times are the "come over" with the adjacent no of drops in the glass.

Cl 35° temp 13°

t 13°

t 13.4°
cold night.
t 10°

24^h. 86400

Residue at ∞ $\begin{array}{r} 197 \\ \underline{3} \\ \underline{200} \end{array}$

h = 3.75 inches

Proportion syphoned off $\frac{2.95}{3.75}$

Wt. of evap. dish 52.181
ditto & residue 52.347

residue 0.166 gms

Equiv. wt. in water

$= \cdot 166 (1 - \frac{1}{\rho}) = 166(1 - \frac{1}{205})$

$= \cdot 166(1 - \cdot 488) = \cdot 166(.512)$

$= \cdot 085$ gms.

$= \frac{.083}{.0222} = 3.83$ drops.

$3.83 \times \frac{3.75}{2.95} \times \cdot 757 = 3.7$

Consider as 3 drops owing to evap. etc.

53

18/1/23.

Sample divided in two parts as equally representative as possible. Orig. wt. too great for getting pts of balance between 0 min + 1 30 min.

Clock 2^{min}.

10^{22}

52 46.

NB $\begin{cases} 45 \text{ drops} = 1 \text{ gm.} \\ 1 \text{ "} = \frac{1}{45} = \cdot 0222 \text{ gms} \end{cases}$

Clock 5^m Whole sample taken again

25 in Clock $24^{m.}$ 3^{52} p.m.

35 20

35 100 in. two little at 20"

Clock 7

35 in 110 " " " "

25 8 120 too much.

42 112 " "

1 32 3 108

2 15 1 100

1

Cl. 10

40

Cl 13.

20	35	35	125
45	4	39	139
1 43	2	41	146
3 18	2	43	153
5 57	1	44	157

This attempt to tie in the previous series of accumulation data with 157 at $6^{00} \equiv 44$ at 5^{57} (allowing for starting the clock after instead of before pouring in the water) shows that the part of the sample separated was not representative but evidently had an excess of the heavy large particles.

35

1 05 6

2 10 2

4 00 1

Repeat with whole sample. Points between 0" and 60" are reqd to carry the graph beyond the value r = 20 μ.

19/1/23

Repeating # 15°

9^{45} am.

Clock 36° 0"

80 in

1.2 20 too much.

1^{20} 85 in Clock 38.

952

1^{50} 85 Clock 40

70 Clock 41

75 15 83

53 5 88

1 14 3 91

35 2 93

58 2 95

2 30 2 97

10 33 am.

35 78 Clock 44

1 7 7 85

1 25 2 87 temp 12°C

50 2 89 Time diff. per drop

2 16 2 91 26 13

43 2 93 27 13.5

3 12 2 95 29 14.5

35 2 97 23 11.5

58 2 99 23 11.5

4 18 2 101 20 10.0

37 2 103 19 9.5

5 23 5 108 46 9.2

5 50 3 111 27 9.0

6 10 2 113 20 10.

Time diff. rate per drop

6 31 2 115 21 10.5

53 2 117 24 12

7 19 2 119 24 12

50 2 121 31 15.5

8 23 2 123 33 16.5

9 3 2 125 40 20

48 2 127 45 22.5

10 53 2 129 65 32.5

12 12 2 131 79 39.5

14 0 2 133 108 54

16 37 2 135

20 34 2 137

27 20 2 139

41 15 2 141

78 30 2 143

1 144 temp

2 146 12.8°C 3 PM.

13°C.

23 hours. not over

Did someone tamper with the tap after I left at 4^{30}?

20/1/23.

Repeating # 15°.

Cl. 52 Time diff. Rate per drop

75 in

40 8 83 35 5

1 15 7 90 14 7

29 2 92 29 14.5

58 2 94 28 14

2 26 2 96

2 98 75 12.5

3 41 4 102 17 8.5

58 2 104 22 11.0

4 20 2 106

2 108 37 9.2

4 57 2 110

10 120

44 10 25 145

1

Cl. 37

75 in

45 7

1 5 3

32 3

2 0 2

Cl. 40 Time diff. Rate per drop

29 75 in 106 12 2

34 6 81 108 temp 13 17 5.7

56 3 84 119 23 7.7

1 19 3 87 123 19 9.5

38 2 89 126 32 16.

2 10 2 91 129 25 12.5

35 2 93 132 30 15

3 5 2 95 134 21 10.5

26 2 97 137

Time diff. Rate per drop

3 46 2 99 20 10

4 5 2 101 19 9.5

45 4 105 40 10

5 0 2 107 15 7.5

19 2 109 19 9.5

32 2 111 13 6.5

6 0 2 113 28 14.

18 2 115 18 9.

43 2 117 25 12.5

7 8 2 119 25 12.5

54 3 122 46 15.3

8 53 3 125 59 19.7

10 12 3 128

12 7 3 131

15 15 3 134

3 136

29 0 2 138

Calculation of r.

temp 13°C $\therefore \eta = 0.01202$

$\rho = 2.05.$

$C = \frac{2}{9}\, 981\, \frac{1.05}{.01202} = 19050$

$r = \sqrt{\frac{h}{Ct}} = \sqrt{\frac{10}{19050\, t}} = .0229 \sqrt{\frac{1}{t}}.$

$F(r) = \frac{2t}{r} \frac{dP}{dt} \frac{dz}{dx}.$

Note. 31/1/23.

The interpretation of F(r) seems to require it to be built up on equal increments of abscissa - r. since an unduly large interval in r sends F(r) up though this does not represent an increased distribution curve over that interval - ∴ it seems that the ordinate to be plotted should be

$F(r_n) \big/ (r_n - r_{n-1})$

8/2/23

Note. See p.65

The above is a misconception. The real no of ptcls is not F(r) but F(r) dr. Hence allowing for irregular intervals dr. plot $\frac{F(r)\, dr}{dr}$ against r that is plot F(r) against r.

If all the successive dr's were the same. plotting F(r) against r or F(r) dr ag. r. would not alter its relative form at all.

23/1/23 Accumulation Curve for # 16.

Clock 12 temp 13°

			time diff	Time per drop
	40			
1. 30	22			
Cl 14	50			
40	~~4~~			
1 18	6			
35	3			
Cl. 16. 1108 am	.5			
40	14	49		
1 3	5	54	23	4.6
25	3	57	22	7.3
54	3	60	29	9.7
2 —	3	63		
50	3	66	56	9.3
3 8	2	68	18	9.0
29	2	70	21	10.5
52	2	72	23	11.5 t. 13.6
	2	74		
4 42	2	76	50	12.5
6 53	4	80	133	25 33.2
7 44	2	82	49	24.5
8 50	2	84	64	32.
Cl. 25				
	42			
1 5	9			
Cl. 27	44			T 14.8
25				
50	7			
1 7	3			

Cl. 32.

15	40
28	9
45	5

Cl. 34 2 25½ pm.

				Time diff temp	Time ~~Rate~~ per drop
					14.4
15	40		15		
28	8	48	28	13	1.6
51	5	53	51	23	4.6
1 15	3	56	75	24	8.0
47	3	59	107	32	10.7
2 27	3	62	147	40	13.3
3 5	3	65	185	38	12.7
	2	67			
4 15	4	71	255	70	17.7
50	3	74	290	35	11.7
5 33	3	77	333	43	14.3
6 26	3	80	386	53	17.7
7 30	3	83	450	64	21.3
9 18	3	86	558	108	36.0
10 44	2	88	644	86	43.
13 18	2	90	798	154	77.
~~16~~ ?	2	92		452	150.7
20 50	1	93	1250		t 14.2
24 50	1	94	1490		
49 0	2	96	2940		14.4
74 ?	1	97			t : 14
	1	98			
20^h	2	100	1°00 overbalanced		
24^h wet over	7	107	do to left		
	−1	106	temp 11.2		
Residue at ℒ	2	108			

h = 3.9 inches ≑ ·991 cm.

Prop^n syphoned off $\frac{2.9}{3.9}$

Wt. of evaporated residue = 52.288 − 52.187 = 0.101 gms

Equiv. wt. in water = $\cdot 101\left(1 - \frac{1}{\rho}\right) = \cdot 101\left(1 - \frac{1}{2.44}\right)$

$= \cdot 101(1. - \cdot 41) = \cdot 0595$ gms.

$= \frac{\cdot 0595}{\cdot 0222}$ drops = ×2.68 drops.

Prop^n wt. wd. have settled on pan

$= \cdot 757 \times \frac{3.9}{2.9} \times 2.68 = 2.72.$

As evap. error, weighing & measuring are all likely to give an overestimate consider as <u>2</u> drops.

Value of r.

1260

Temp. app. 14°C ∴ $\eta = 0.01171$.

$\rho = 2.44$

$C = \frac{2}{9}\, 981\, \frac{1.44}{.01171} = 26820$

$r = \sqrt{\frac{h}{ct}} = \sqrt{\frac{10}{26820}}\sqrt{\frac{1}{t}} = 0.0193\sqrt{\frac{1}{t}}.$

Notes on curve $\frac{F(r)}{r_m - r_{m-1}}$ against r show that 37% have radii $> 36.3\,\mu$.

1.85% " " $< 0.65\,\mu$

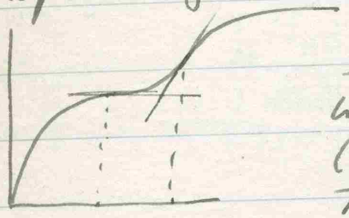
Of remainder majority have limits $5 < r < 10\,\mu$ + interval 11.3 μ to approx 14 μ shows no particles - definite zero at 11.3 - from 14 μ — 36 μ very small propn but evidently somewhere beyond that there wd. be a decided maximum nearly as great as that about 9 μ.

Try to find upper limit for r by microscope.

See note p. 57. Replot this curve

3/2/23.

Note. The interpretation of the neg. values of $\frac{d^2P}{dt^2}$ before the zero value wd point to a previous zero value just before thus



2 pts of inflexion with the concave curve (upwards) between them.

What is happening to $\frac{dP}{dt}$ meanwhile? Since $\frac{dP}{dt}$ registers the actual settling process & at time t there are all sizes besides those with radius corresponding to time t, we cannot expect $\frac{dP}{dt}$ to vanish because there are no ptcls of a size r (at time t)

Hence the above interpretn based on the behavior of $\frac{d^2P}{dt^2}$ seems likely. & the interval over wh. there are no ptcls of radii r_t to r_{t+dt} extends from just before the first neg value to the zero value - gtr precision in measurement should show up these two zeros.

5/2/23

The above is not quite right. If $\frac{\partial^2 P}{\partial t^2} = 0$ it means that $\frac{\partial P}{\partial t}$ is linear & this Sven Oden interprets as meaning that $F(r) = 0$ over the $r_m - r_{m-1}$ interval concerned.

1/2/23 Pelagic Ooze #6.

Clock 11^{28} 25

	20
145	80

Cl. 27

		P	time	dt
	60	60		
45	26	86	45	
1 5	6	92	65	20
32	6	98	92	27
2 4	4	102	124	32
45	4	106	165	41
4 15	4	110	255	90
45	4	114	285	30
5 45	4	118	345	60
6 37	3	122	397	52

Cl. 36 2^{20} pm

			time	
40	75	75	40	temp 17°C.
1 7	8	83	67	
27	4	87	87	
56	4	91	116	
2 36	4	95	156	
3 15	3	98	195	
57	3	101	237	
4 ?	2	103		
5 16	4	107	316	
	3	110		
6 35	3	113	395	
7 20	3	116	440	
53	2	118	473	
8 30	2	120	510	
9 25	3	123	585	
10 38	3	126	638	
12 8	3	129	728	
14 24	3	132	864	
16 50	2	134	1010	
19 19	1	135	1159	
21 7	1	136	1267	temp 17°C
25 55	1	137	1555	
36 0	1	138	2160	
	1	134		$2^h.34^m$ not over.
24h.	1	140	86400	temp 17°C.
Residue	6	146		19^h t 16.7
				24^h not over.

h = 3.7 inches = ·94 cm.

Propn syphoned off $\frac{2.8}{3.7}$

Wt of residue = 44·1385
43.9202
.2183 gms

Equiv. wt. in water = $\cdot 2183\left(1-\frac{1}{\rho}\right)$

$= \cdot 2183\left(1-\frac{1}{2.75}\right)$

$(1 - \cdot 364)$

$(\cdot 636)$

$= \cdot 139$ gms $= \frac{\cdot 139}{0222} = 6.26$

Propn. wh. wd. have settled on pan

$= 6.26 \times \cdot 759 \times \frac{37}{28}$

= 6.26 drops.

= 6 drops.

Total menge

Value of r.

temp 17°C $\eta = \cdot 01082$ $\rho = 2.75$

$$C = \frac{2}{9}\, 981\, \frac{1.75}{01082} = 35250$$

$$r = \sqrt{\frac{h}{ct}} = \sqrt{\frac{10}{35250}}\sqrt{\frac{1}{t}} = \cdot 01685\sqrt{\frac{1}{t}}.$$

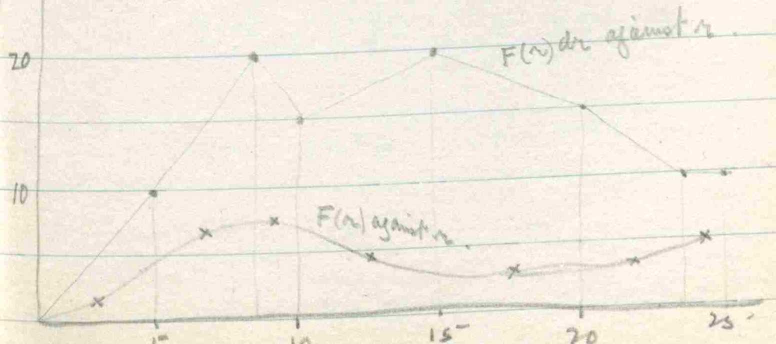
8/2/23.

Note the following illustration of meanings of F_r + $F(r)\,dr$ + dr + the resulting curves –

100 particles (see p. 57)

Limits	dr	$F(r)\,dr$	$F(r)$	$\frac{F(r)}{dr}$
0–5 μ	5	10	2	·4
5–8	3	20	6.7	2.2
8–10	2	15	7.5	3.7
10–15	5	20	4	·8
15–20	5	15	3	·6
20–23	3	10	3.3	1.1
23–25 μ	2	10	5	2.5
		100	31.5 meaningless	

Plot at mid points of dr.
To plot $\frac{F(r)}{dr}$ would give a
curve with no meaning of
any value whatever.



8/2/23

Test on Rock C-138
Ground up by GVD for assay test.

11^{36}

Clock $^{29\ 31}$ 28

	20		temp 14.8
	25		
40	10	55	
	7	62	
58			
1.18	5	67	
42	4	71	
2.24	4	75	
3.15	3	78	
	2	80	
	2	82	
9.30	1	83	
10 20	1	84	
14 30	1	85	
	2	87	
51.0	1	88	
	3	91	
	2	93	Brought it over at 9^{45} am.

17/2/23.

Contd. from p. 47.

1 cm travelling scale = .991 cm. actual.

Z. 2. large clear crystals like sugar – Quartz (? $\frac{?}{40}$).

(1) 7.052 – 7.03 = .022 cm.

(2) 7.072 7.046 = .026 cm.

(3) 7.046 – 7.104 = .058 cm.

(4) black 7.104 – 7.064 = .04 cm.

(5) clear 7.064 – 7.126. = .061 cm

(6) " 7.126 – 7.172 = .046 cm

(7) " 7.172 – 7.256 = .083 cm.

(8) black 2.52 – 2.50 = .02 cm

(Black ones do not seem to be magnetite). Tested with a U-mag mag without result) No sign of organic shells.
Magnetized end of hat pin & picked them all up – ∴ Magnetite

20/2/23.

Z.4. Contd from p. 47.

There seem to be very few large clear or black ptcls as so numerous in Z.2. but finer ptcls seem as though peppered with magnetite + also some very scintillating crystals.

Clear. 2492 2470 = .022

Z.6. Ptcls of black magnetite.

(1) 2492 - 2512 = .020 cm

(2) 2512 - 2524 = .012 cm

(3) 2524 - 2540 = .016 cm.

(4) 2540 - 2512 = 028 cm

(5) 24~~92~~26 - 2444 = .018 cm.

Very few coarse clear crystals.

(1) 2537 - 2511 = .026 cm.

Z.16. No magnetite ptcls.

Some beautifully preserved large globigerina shells oval, globular, kidney-shaped + acorn shaped.

(1) 2444 - 2480 = 036 cm.

(2) 2494 - 2526 = 032 "

(3) 25~~26~~30 - 2603 = 073 "

(4) 2472 - 2524 = .052

Z.15. Very few exceptionally large. many about .02 cm. No magnetite

(1) 2514 - 2588 = .074.

Z.14. No magnetite. Very like Z.15.

(1) 2624 - 2688 = 064 cm.

Z. 9. Weddell Sea? Long. 45°. W.
Very fine altogether – hardly any magnetite & no quartz crystals as in Z. 2.

(1) Mag. 2692 – 2714 = .022.

Z. 10. Also very fine no coarse ptcls whatever. a few very fine mag.

plasticity

Z. 6. augite in qtz pebble river pebble 2 mm ~~2 mm x~~ long.

Z. 15. fine globigs & arkose with white mica 1 mm long –

Z. 2. Quartz
Magnetite
Obsidian
Olivine } Coarse ptcls

Points to be noted at Rothamsted Experimental Station
Harpenden.

1. Apparatus – a. range of mass
b. temp control –
c. insertion of suspension.

2. Theory – a. Approximation of σ_1
b. Effect of Colloidal suspensoid on η.
c. Pt. of inflexion . or

d. Range of sizes graded – (1 μ to 40 μ)
e. Graphic proceedure ?

3. Practical applications to Soils –

Apr. 3rd/23. Rothamsted Experimental Station
Lawes Agric. Trust – Harpenden.
Dr B.A. Keen.

1.a Range of Mass. 5 gms maximum
accuracy to 2 mg.
Concentration should not exceed 2%
i.e. 5 gms to 1 litre gives results as
if each particle were falling free – gtr. concn
means interference + change in viscosity.
b. Apparatus in basement in constant temp
room.
c. well shaken in a double ended shaker
+ poured in + stirred + then pan immersed
(my way seems preferable?)

2/a σ. by a spec. gravity bottle first
having got rid of air by placing in a
larger vessel + evacuating.

b. see 1.a.

c. Dr Keen says that mathematically there should never be either a cusp or pt. of inflexion even when $F(x) = 0$. merely an interval of str. line. But evidently Sven Odén has also found this & attributes it to some as yet unexplained experimental change.

d. within my range as yet. Terminology of "clay" is diam. < ·002 mm. Other groups in rough mechanical analysis are sand, fine sand, silt, fine silt, clay.

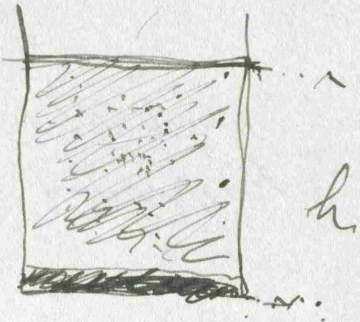
e. Admitted the procedure whether graphic or arithmetical or both (as in my case & I think in his also) as very cumbersome & said Odén & he were going to try to devise a simpler method next fall.

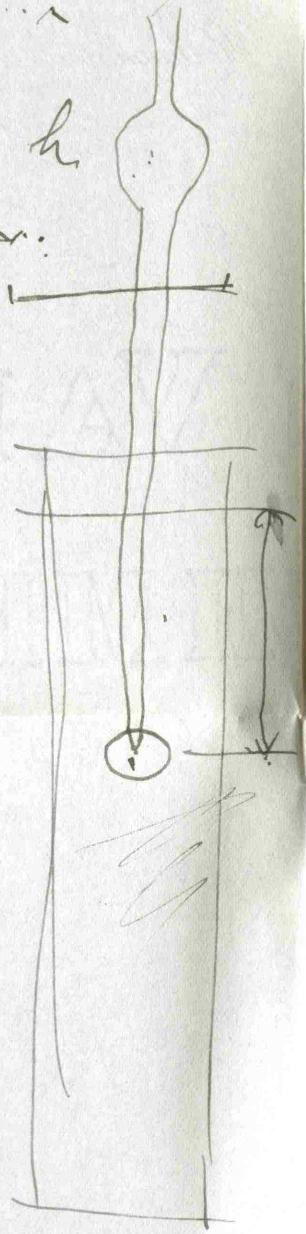
3. Correlation betw. distrib^{n} of sizes & moisture content is important but as yet no data available nor for fertility of soil – though he knows a very zig-zag distrib^{n} curve would probably not represent as good a soil agriculturally as a more even one.

New form of apparatus.

Suggested by Sven Odén to Faraday Soc. & carried out by Dr Keen thro the Cambridge Sci. Inst. Co. Cost £200.

The left hand pan is suspended by a long triple suspension passing thro a hole in the floor of the balance case into the thermally insulated sedimentation vessel. The right hand arm carries a vertically suspended bar magnet partly within a solenoid.

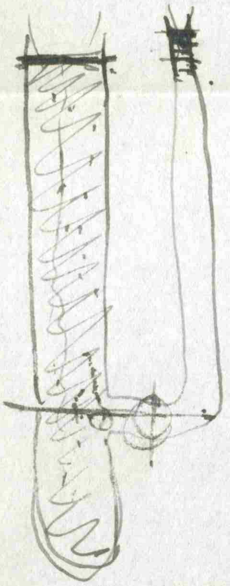




10 mm.

1/m

1·0 2·7



Sand fm : clay

< - > K 0·02 > ·002 →

·2 – ·02 ·02 ·2 ·02

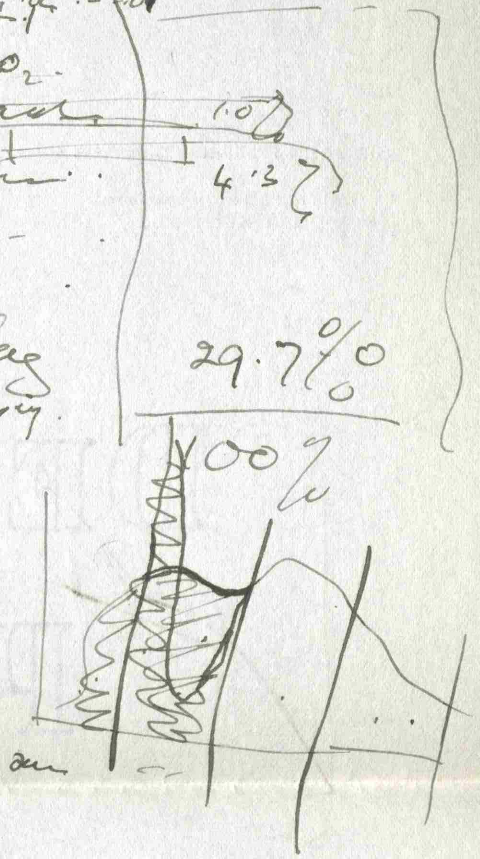
CuCO₂

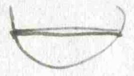
sand 1·0

fine 4·3

clay losing

29·7%





sand.

Telegrams: LABORATORY. HARPENDEN.
Telephone: 21 HARPENDEN.

Railway Station:
HARPENDEN (MIDLAND RAILWAY).

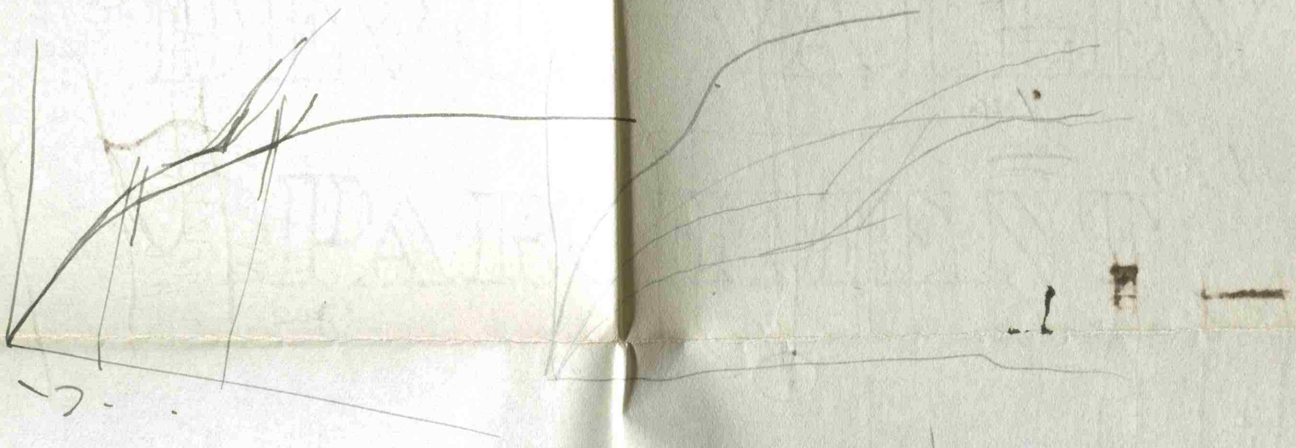
Lawes Agricultural Trust.

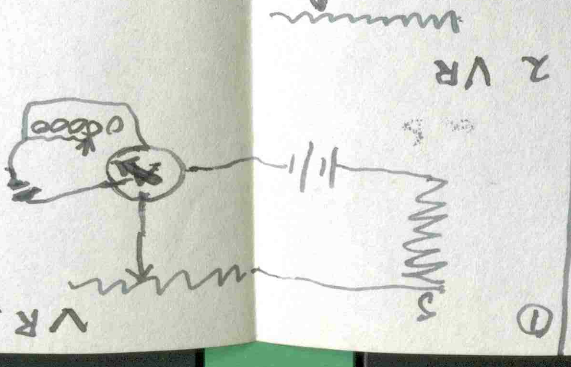
Director:
SIR JOHN RUSSELL. D.Sc., F.R.S.

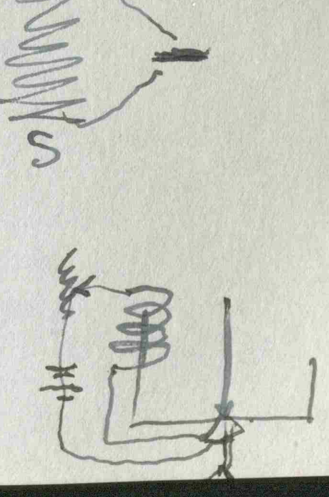
Head of Physical Department:
B. A. KEEN, D.Sc.

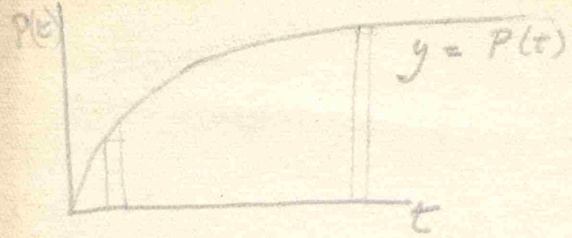
Rothamsted Experimental Station
Harpenden.

....192..







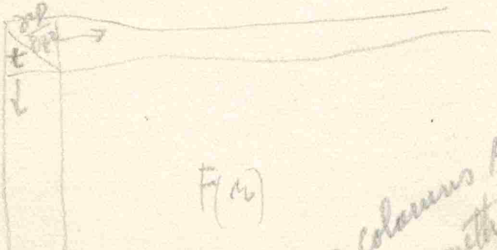


$F(r) = K\, t^{5/2} \frac{\partial^2 p}{\partial t^2}$

Cols. req.d for this Evaluation

1 t' 2 t 3 $t_n - t_{n-1}$ 4 Diff. 5 P 6 $P_n - P_{n-1}$ 7 $\frac{\partial P}{\partial t}$ 8 Diff.s/2 9 $\frac{8}{3}$

10 $t^{5/2}$ 11 $F(r)$ 12 (r) 13 Midpt. of dr



2 columns saved – but value of this method turns on whether same accuracy is pos. in differencing $\frac{\partial P}{\partial t}$ as in log. Look this up

Range of values of t is.

0" to 86400" i.e. 24 hours.

Going up by small increments until after 10th min. i.e. 20" = dt. for 1st 5 min then 30" or 40" increments

beyond 10th min 100" increments to 30th min Then 300" increments.

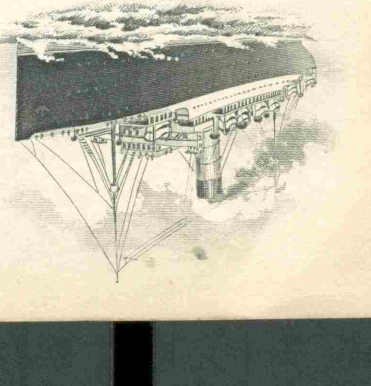
Range of values of $\frac{\partial P}{\partial t}$

① %	② t	③ $P_n - P_{n-1}$	④ $t_n - t_{n-1}$	⑤ $\frac{\partial P}{\partial t}$	⑨ $\frac{\partial^2 p}{\partial t^2} = \frac{⑧}{④}$
25	20"	5	10	0.5	$\frac{.24}{15} = .016$
30	30	4	15	0.26	$\frac{.14}{25} = .0056$
34	45	3	25	0.12	
33	70				

⑥ Diffs.	⑦ Diffs	⑧ Diffs	⑩ $\partial^2 p / \partial t^2$
1	5	0.24	0.048
1	10	0.14	0.014

Method 9 for 2nd derivative seems correct not method 10.

~~i.e. take 2nd diffs of P + divide twice~~



ON BOARD THE
CUNARD
R.M.S. "ANDANIA"

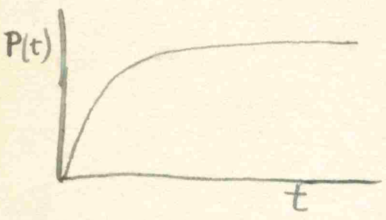
$$F(r) = -\frac{2t^2}{r}\frac{d^2p}{dt^2} = -\frac{2t}{r}\frac{dP}{dt}\frac{dz}{dx}$$

where $z = \log\frac{dP}{dt}$, $x = \log t$ $\Big\}$ $\frac{dz}{dx} = \frac{1}{\frac{dP}{dt}}\frac{d^2p}{dt^2}\,\cancel{1/t}$

$$= \frac{t}{\frac{dP}{dt}}\frac{d^2p}{dt^2}$$

$\therefore$ $F(r) = \frac{2t^2}{r}\frac{d^2p}{dt^2}$ involves $t, r, \frac{d^2p}{dt^2}$.

If t = const. $F(r) = K\frac{\frac{\partial^2 p}{dt^2}}{r}$



$r = \sqrt{\frac{k}{ct}} = k_1\sqrt{\frac{1}{t}}$

$\therefore F(r) = -k\,t^{5/2}\frac{d^2p}{dt^2}$

$F(r) = \text{const}\left\{t^{5/2}\frac{d^2p}{dt^2}\right\}$

$= \text{const}\,(x\;y)$ where $x = t^{5/2}$, $y = \frac{\partial^2 p}{dt^2}$

If x = const.

$F(r) = \text{const}(y)$ = st. line. A

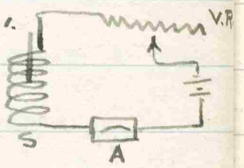
If y = const.

$F(r) = \text{const}(x)$ = st. line. B

+ Pt of intersection of a line A with a line B is $F(r) = \text{const}(x_A y_B)$

The solenoid circuit consists of a variable resistance, accumulators to supply the current + an ammeter (as a magnet + not a coil is suspended, the current + not the square of the current is a direct measure of the weight of the pan + sediment.) fig. 1.

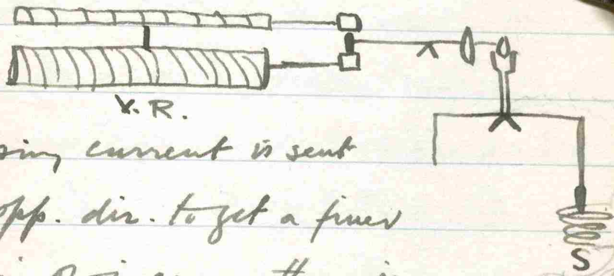
1.



The variable resistance is automatically adjusted thus: An inverse pointer goes up carrying two mutually insulated wires the ends of which are one on either side of a small rotating wheel of brass (rotation ensures good sliding contact + no sticking of wire to the brass) These connect by a very flexible wire to the solenoid (?) while the rotating wheel connects to an electromagnet pivoted between two poles. it is a friction wheel + whichever pole it makes contact with it sets rotating its axis connects with the axle of a cylinder wound with wires of certain length + pitch so that either one turn of the variable resistance is added or cut off according as balance beam went down on right or left. fig 2.

200 volt mains ?

2.



An opposing current is sent thro in opp. dir. to get a finer gradation of increase than is represented by one complete turn on the big drum.

The ammeter is the usual self-recording instrument with this addition that the range 0 to 0.2 milliamps can be increased 25 times giving a total range of 0 to 5 milliamps - read on the graph as a series of increases from the zeroline

This is effected by having the pointer which by clockwork is pressed down on an inky thread onto the graph at regular intervals, - make contact at the extremity of its range with a circuit governing a ratchet which cogs with a key which throws in or out one more of the 25 similar coils within the ammetre.

There is furthermore a means of checking the whole E.M.F. + compensating for variations. The 200 volt circuit was used.

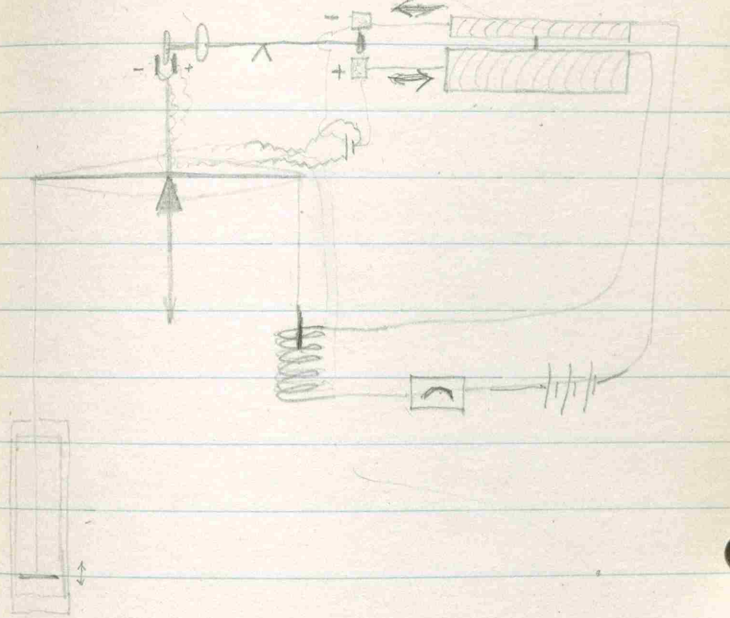
Advertised as a Continuous Weighing Balance

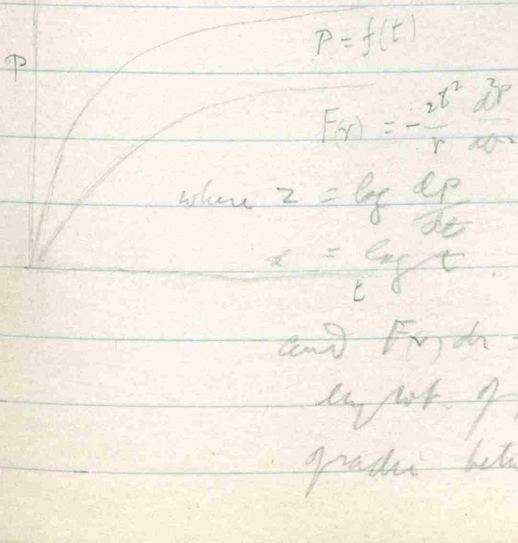
References given by Dr Keen.

General Articles: Journal of Agric. Sci (Camb. Univ. Pres)
Soil Science
J. Agric. Research (Biological)

Routine Method of mech. analysis: J. A. Sci. Vol 1 or 2.
Robinsons Modification of above: J. A. Sci. 1922·3
Odens Method: R. Soc. Edin. 1915.
& general communications: Physico-chem. problems relating to the Soil. Faraday Soc. 1922.
Inter. Mitt. für Bodenkunde.
Wiegner's Method: Exp. Stat Record (U.S. Dept. Agric)
Int. Inst of Agric. Rome (Agric. Intell. & Plant Disease Series)

Better diagrams from p. 78, 79.





$P = f(t)$

$$F(r) = -\frac{2t^2}{r}\frac{d^2p}{dt^2} = -\frac{2t}{r}\frac{dp}{dt}\frac{dz}{dx}$$

where $z = \log \frac{dp}{dt}$

$x = \log_e t$

and $F(r)\,dr$ = propn by wt. of particles of radii betw r, $r+dr$

Telegrams: LABORATORY. HARPENDEN.
Telephone: 21 HARPENDEN.

Railway Station:
HARPENDEN (MIDLAND RAILWAY).

Lawes Agricultural Trust.

Director:
SIR JOHN RUSSELL, D.Sc., F.R.S.

Head of Physical Department:
B. A. KEEN, D.Sc.

Rothamsted Experimental Station
Harpenden.

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General articles in Journal Agric. Science
(Cambridge Univ Pr[illegible])

& J. Agric. Research (Biological)
Soil Science.

Routine method of mech analysis in J. A. Sci.
Vol. I. & 2

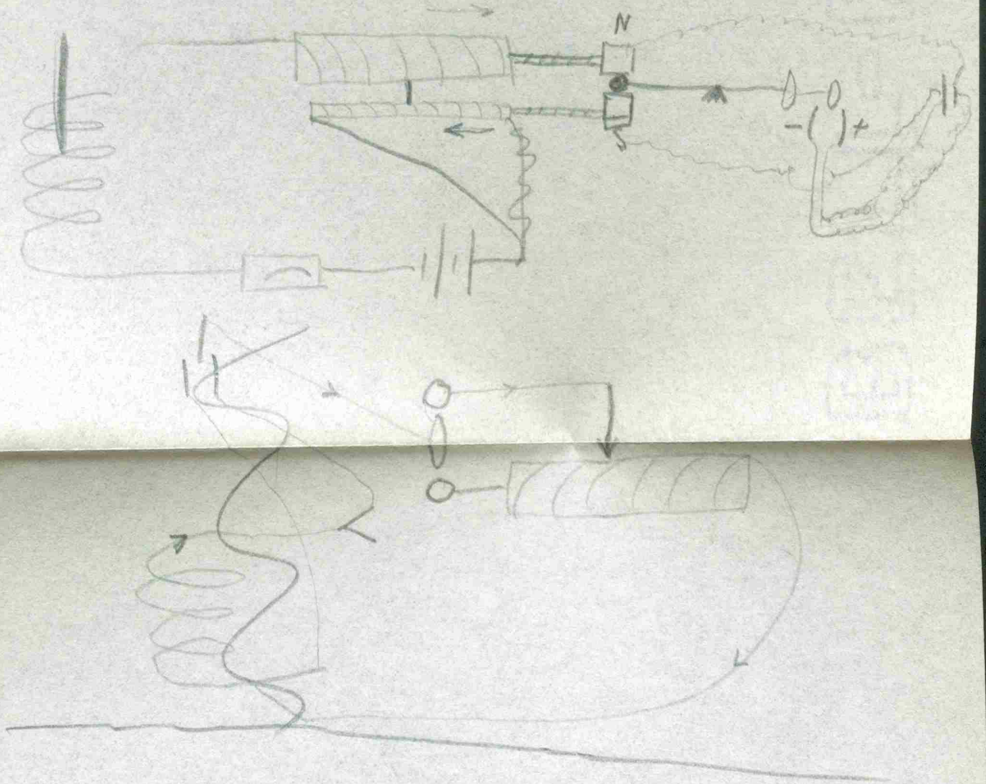
Robinsons modification of above in J. A. Sci. 1922-3

Odén's method
& general considerations

R. Soc. Edin. Papers (1915)
Physico-chem. problems relating to the soil
Faraday Soc. (1922)
Int. Mitt. für ~~Boden~~ Bodenkunde.

Wiegner. method.

Exp. Stat. Record (U.S. D. Agric)
Rome Int. Inst. of Agric. (Agric. Intell. & Plant Disease series)


N
S
– ( ) +

Further note on Experimental procedure as sent to Dr Keen, Rothamsted (June 1923)

In order to reduce to a minimum the time lost at the commencement of an experiment ~~two precau~~ the following procedure was adopted. Preliminary tests ~~showed that about 15 sec were required to get~~ were run to ascertain the number of drops required to counterbalance what settled within the first 10 or 15 seconds + then (this ~~the~~ amount was inserted before commencing*) the water containing the suspension was then thoroughly shaken + rapidly poured into the vessel ~~into~~ which ~~the pan is suspended~~ was raised up about $\frac{1}{4}$" just enough for its bottom to support the suspended balance pan. The vessel was then lowered to its stand + the balance arm released. ~~when the counterbalancing weight had been properly calculated~~ It should then be about in equilibrium + readings could be at once begun.

* This precaution was essential where the sample contained a large amount of coarse particles falling almost instantaneously since the time required to insert onto the ~~small~~ 2nd pan some 30 separate drops ~~was~~ considerab

of sea water, otherwise such a gap as that found by Sven Oden and in part confirmed by this investigation would be most improbable.

In the following table, summarizing the results shown graphically below, the value of r given is the mid-point of the interval dr corresponding to the value of F(r) and is measured in terms of μ as unit.

Table of F(r) and r.

	Z_2		Z_4		Z_6		Z_{14}		Z_{15}		Z_{16}	
	F(r)	r	F(r)	r	F(r)	r	F(r)	r	F(r)	r	F(r)	r
% ungraded												

% ungraded

In conclusion the writer has pleasure in expressing gratitude to Professor Sir E. Rutherford for permitting the carrying out of the investigation in the Cavendish Laboratory; to Dr C.T. Heycock for the loan of a balance from the Metallurgical Department; and to Mr G. Vibert Douglas who ~~not only~~ provided the material ~~but~~ and drew attention to the work of Dr Sven Oden ~~and~~ when suggesting the ~~above~~ investigation.

over

Sample Z.15. Lat. 35°40'S. Long. 5°01' W. 1942 fathoms.
A globigerina ooze with much terriginous deposit — density 2.05 — 50% by weight ~~has~~ is made up of particles having radii less than 43 μ. It is evident from the curve that there is ~~a greater~~ maximum distribution between $r = 2\mu$ and $r = 11\mu$, ~~From $r = 13\mu$ to $r = 15\mu$~~ and there appear to be no particles within the range $13{\cdot}3\mu < r < 15{\cdot}2\mu$ though the curve gradually ascends beyond the latter value to $r = 40\mu$. 1.5% having radii less than 0.8μ had not settled within 24 hours.

Sample Z.16. Lat. 35°41'S. Long. 5°10' W. 1989 fathoms.
A globigerina ooze with some terriginous material — density 2.~~75~~44 — 43% by weight consists of particles having radii less than 50μ and these cluster chiefly about the range $2\mu < r < 11\mu$, there being apparently no particles within the region $11.3\mu < r < 15{\cdot}8\mu$. ~~and beyond that~~ 1.85% was found to have radii less than $0{\cdot}65\mu$ and had not fallen after the elapse of 24 hours.

These three fall naturally into one group as did the former and have the following features in common (1) From 35% to 50% is composed of relatively coarse particles falling within the first 25 seconds (if $h = 10$ cms). (2) Of the finer particles the distribution is greatest within the range $2\mu < r < 11\mu$. (3) In one case there are comparatively few and in the other cases no particles recorded having radii approximately $13\mu - 15\mu$. This result is of special interest because Sven Odén found a complete absence of ~~globigerina ooze~~ particles having radii within $12\mu < r < 20\mu$[3] for globigerina ooze from the Atlantic Ocean, a range embracing that obtained by the writer in the case of Z.15 and Z.16. This ~~would look as though~~ suggests that this genus of Foraminifera are of two classes — "giants" and "dwarfs" — and that the former at least are only slightly ~~acted upon~~ affected by the dissolvent action

Sample Z.2. Lat. 67°40' S. Long. 17°0' E. 2356 fathoms.

A diatom ooze with considerable terrigenous material — density 2.53 — 70% by weight is composed of particles with radii less than 22 μ (μ = .0001 cm) The distribution curve shows the maximum to be at about 2.0 μ and the minimum at about 14.0 μ. 2% has radii less than 0.7 μ and was still in suspension after 24 hours.

Sample Z.4. Lat. 69°8' S. Long. 17°4' E. 1089 fathoms

A diatom ooze with considerable terrigenous material and a large amount of very fine particles which keep the water opalescent even after several days standing — density 2.67 — 60% by weight is composed of particles with radii less than about 22 μ. The curve indicates a maximum at 0.6 μ and at 4.4 μ with a pronounced minimum 6μ to 8μ. ~~a minimum between~~ [illegible] ~~and another~~ 3% has radii less than 0.46 μ and had not settled after 42 hours. This sample ~~Sample Z.4~~ came from the furthest point south that has ever been reached at that longitude.

Sample Z.6. Lat. 66°52' S. Long. 14°27' E. 2341 fathoms

A mixture of diatom & terrigenous ooze — density 2.75 — 50% by weight is composed of particles with radii less than about 23 μ. The curve shows a main maximum at about 6.0 μ and minimum at 11.0 μ. 4% has radii less than 0.57 μ and had not fallen within 24 hours.

These three ~~all~~ show certain common features: (1) about half the weight settles ~~when h = 10 cm,~~ within ~~inside~~ the first 45 seconds (h = 10 cm) and is composed of particles having radii greater than 23.0 μ. (2) of the finer particles the majority cluster about the sizes given by ~~both~~ $2\mu \leq r < 6\mu$ and within this range there are two maxima, this "Kink" being a feature of all curves & appearing also in Sven Odens curve for "Boden" & "Kosta". ~~though at a greater value of r~~. (Ref. *2. p. 298.)

Sample Z.14. Lat. 39°13' S. Long. 10°28' W. 1880 fathoms.

A globigerina ooze with considerable terrigenous material — density 1.93 — 70% by weight is composed of particles having radii less than about 60 μ. The curve indicates maxima at 2 μ and 4.5 μ. and it runs fairly close to the abscissa throughout the range 9 μ to 35 μ ~~with~~ almost touching it at about 28 μ. 2% has radii less than 0.8 μ and remained in suspension after 24 hours.

has nevertheless seemed to the writer that it was worth while following Sven Odén's method in view of the extraordinary consistency of the results, the large number of particles involved *8. and the fact that especially in ~~for~~ Globigerina ooze the predominance of spheroidal forms is very marked. (see plates XII – XV. [illegible]

Experimental Arrangement.

The apparatus employed by Sven Odén ~~consisted~~ depended on ~~of~~ an ~~mat~~ automatic electrical release whereby counterbalancing weights were introduced onto the 2nd pan of the balance as the particles were deposited on the immersed pan. The writer has substituted a very simple and apparently satisfactory method of compensation consisting of allowing one or more drops of distilled water to fall from a small orifice, at the end of a drawn-out glass tube joined to the base of an ordinary burrette, into a small beaker on the second balance pan. The times when successive drops were required in order to maintain a balance were noted, also the number of drops, and

---

*8. In a sample of deposit weighing 10 gms whose average density is 2.6 and whose average radius is 20μ the approximate number of particles is
$N(r) = F(r)/(\frac{4}{3}\pi r^3 \sigma) = 10^8$

these two items provide the data from which the accumulation curve can be obtained. Readings were taken at intervals over 24 hours at least and to the cumulative total was added the equivalent weight of the residue which would have settled in the pan

Then the major portion of the water was syphoned off & the amt. of undeposited residue obtained. → Thus giving the value of $P_\infty = 100\%$.

It was found that the ~~weight of the~~ drops formed a sufficiently accurate scale of weights and by using a glass receptacle of very small diameter the correction for evaporation loss over 24 hours was practically negligible.

Results

~~Sixteen~~ bottom samples were brought home by the Quest. They included ~~Of the~~ thirteen samples of pelagic deposits ~~brought home by the Quest~~ of which seven consisted of such minute quantities that when slides had been made there was little or nothing left. The other six, however, varied from 10 to 25 gms each. Their densities were ~~first~~ determined by means of a pycnometer.

which had been obtained in collaboration with the Hydrographer [*5] should be ~~analysed~~ examined by the above mentioned method. ~~and~~ They were accordingly given to the writer for this purpose.

Outline of Method ~~theory~~.

One pan of a balance is placed near the bottom of a vessel ~~of depth h~~ containing an aqueous suspension of the sample. By continuous weighing the rate of deposit on the pan is obtained and this cumulative weight P~~(t)~~ is plotted against t forming an "accumulation curve". The following points have been ~~established~~ made by Dr Sven Odén :– [*2,3.]

(1) If h the height of the water column above the pan be varied the accumulation curve for any given sample remains practically unaltered if the values of t for the abscissa are reduced to some standard value of h (say h = 10 cm) by the factor $\frac{10}{h}$

(2) The accumulation curve is independent of the total weight of the sample within reasonable limits if P be the percent of the total weight which has accumulated at any given time t.

(3) Care must be taken to avoid or correct for temperature ~~changes~~ variations since the rate of fall varies inversely as the viscosity, and for water this changes very rapidly ($\eta = 0.01307$ at 10°C to 0.01004 at 20°C)

(4) The "effective radius" calculated from Stokes' Law $v = \frac{2}{9} g \frac{\sigma_1 - \sigma_2}{\eta} r^2$ has a real physical significance when the number of particles dealt with is so great as to render the investigation statistical rather than individual.

(5) From the accumulation curve P~~(t)~~ = f(t) it is possible by a mathematical analysis to obtain a function F(r) such that the area F(r) dr represents the proportion by weight of particles having an effective radius between the limits r and r + dr. It is found that $F(r) = -\frac{2t^2}{r}\frac{d^2P}{dt^2} = \frac{2t}{r}\frac{dP}{dt}\frac{dz}{dx}$ where $z = \log\frac{dP}{dt}$ and $x = \log t$, the auxiliary curve (x, z) being adaptable for graphic treatment.

It has been objected by Professor C. G. Knott [*6] that the use of Stokes' law may give entirely fallacious results due to the irregular shapes of the particles many of which may be of flat flaky form. This objection is emphasized by the recent success of Dr E. W. Wetherell[*7] in photographing the tracks of flat solids falling through water. It

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*5. Commdr F.A. Worsley, DSO.

*6. Proc. R. S. Edin. XXXVI. p. 237. (1915–16).
*7. Nature. Dec. 23. 1922. p. 845.

The Sizes of Particles in certain Pelagic Deposits.

Introduction

The monumental work of the late Sir John Murray[*1.] and Mr Renard in the examination and classification of deep sea deposits has left little to be desired both as regards methods and results. There was, ~~however~~ one respect in which they were handicapped — no satisfactory method was known ~~whereby~~ of ascertaining the distribution of sizes of the particles of which a sample was composed. ~~could be ascertained by a very inexact~~

In 1915 Dr Sven Odén[*2] of Uppsala made known a very beautiful method of soil analysis whereby he obtained by a sedimentation process data from which he could construct the distribution curve representing the relative proportions of particles of various sizes. He later obtained from the Challenger Office several samples of different types of deep sea deposit which he subjected to the same form of analysis. His results[*3] were of great interest not only because each type of clay or ooze showed a distinctive form of curve but also because the same type of deposit exhibited definite peculiarities according to which the Ocean from which it had come ~~from~~

On the return of the "Quest" (Shackleton-Rowett Antarctic Expedition, 1921-22) it was thought desirable by the geologist of the Expedition[*4.] that the samples of deep sea deposit

---

[*1.] Challenger Reports ~~XXII.~~ (1891) Deep Sea Deposits. Report of Scientific Results of H.M.S. Challenger (1873-76)

[*2.] International Reports on Pedology. V. 4. 1915. p. 257. (Obtainable on loan, in german, from the Ministry of Agric. + Fisheries, 10 Whitehall Place. London. S.W.1.)

[*3.] Proc. R. S. Edin. XXXVI. p. 219. 1915-16.

[*4.] G. Vibert Douglas, M.C. M.Sc.

·THE·PHYSICS·OF· ·STELLAR·ATMOSPHERES·

A. V. Douglas.

A. V. Douglas.

Cavendish Lab.
Lent Term 1923.

Index

p. 37-3. Refs to Saha on Ionization.
p. 39 Summary of Saha Temp. theory.

p. 63 Potsdam temps

p. 65. Heat from Stars – ang diam. + temp
Refs. to Thermopile work, Colour index etc etc.

p. 76. Spec. //x refs.

The Physics of Stellar Atmospheres.

Mr A.E. Milne.
Trinity
22/1/23.

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The Sun:

Abbot: 1911 N. York very readable
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Emden : Gaskugeln - Leipsig 1907 ?
mathematical.
Jeans Cosmogony.

Astrophysical Journal (60 vols)

Outline of Course

The Sun
Stars spectral class.ⁿ
line spectra
continuous spectra.
temps & intensity.
Pressures.
Ionization.
Angular diams
Scattering & absorption
apparent brightness.
Variable stars, nebulae & miscellaneous.

The Introduction.

History of development of stellar physics.
Fraunhoffer lines

1860 Kirchoff explains them as equiv. to the bright lines of individual elements.

Norman Lockyer : Chem of Stars.

Two main contributions ~~Kirchoffs empirical~~ of Physics

1. Princ. of empirical spec. analysis
2. Döppler Fizeau principle about 1830.
Vienna

2. originally applied to sound. later misapplied to stars - approaching star has shift of intens towards blue - but no total change of colour. At first it was argued that all red stars were departing & all blue stars approaching. Actually for every shift in a certain dirⁿ: more lines enter from the other direction.

1869-70 First spectral photograph of star. continuous.

Huggins - account of his first view of a spectrum of gaseous nebula. lines only hence he concluded its gaseous nature.

Results of 1 + 2.

1. Chem compos. of atmos. of Sun & stars. Essential similarity between the diff. parts of the universe.

Lockyer's discov. of He in Sun.
Pickerings " of ζ Puppis He^+

2. Gaseous nature of certain nebulae – i.e. bright line spectrum

3. Radial velocities of many bright stars
Order of mag. 20 Km/sec.

4. Discov. of spectroscopic doubles.
(Lines alternately moving apart & together)

First double star thus found } Ursae Maj. middle of handle of plough.
Pickering

5. Invention of spectroheliograph
Structure of Solar atmosphere.

Progress depended on advance in photography.

Recent discoveries in Physics bearing on astrophysics.

1. Planck's law of radiation (leading to Q. Thy.)
Hence "effective temps of stars"
including all the applications of macroscopic radiation theory
i.e. why w^{d} expect star to behave as a black body
laws of scattering etc.
Kirchoff's laws.

2. Zeeman effect: magnetic fields on the Sun (general & special at sun spots)

3(a) Stark effect – analogue of 2 for electric field
(continuous spectrum produced by superposition of many random spectra due to chaotic el. fields about indiv. atoms)

3. Quantum theory of line spectra H, He.

4. Theory of ionization + enhanced lines (Saha)
generalized photoelectric effect.

5. Pressure of Radiation
(established at Harvard).

Contribution of Stellar Phys. to Physics.

various unknown lines (green of corona + of aurora)

Pickering's work.

Theory of resonance spectra
fluorescence

Radioactivity as a poss. source of energy.
gravitational energy not sufficient.
synthesis of heavy atoms in stars.

Photoelectric cells

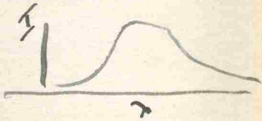
Interferometer for ang^lr diams.

Spectroscopic parallaxes -

Light has intensity, wavelength polarization & phase & these give all the req^d data.

1. Analysis of each λ.
2. Total intensity.

Combining these get



3. Polarization
   not from Sun or Stars, possibly from corona.
4. Phase composition
   giving ang. diam of stars by interference bands.

If these are fully explored there will be nothing further unless a method of extending the Spectrum.

The Sun

Not a typical star - hence danger of generalizing from data obtained from it.

Radius 700.000 Km.

(Probable radius of Eddington's typical star
mass 1½ × mass of Sun
radius 7,000,000 km.)

Diam - ½° 30'
1" 725 Kms.
1' 40,000

Prominences.

Mass of Sun 2×10^{33} gms -
density 1.4
for earth 5.5

Hence gravity at surface of Sun 27.6 × g.

Vel. for escape of a body from surface of sun 600 Km/sec.

Such a high density makes it difficult to account for the great height of the solar atmosphere.

24/1/23

Solar constant is defined as the energy reaching the Earth per sq cm per min in calories & corrected so as to allow for loss in Earths atmosphere.

Difficult of measurement. In 100 yrs values varied from 1.7 to 3. Mean for last 11 yr Solar cycle is 1.94 Abbot. Smithsonian Astrophysical

Vols. I – IV specially IV

Having Solar const. we can calculate the effective temp i.e. temp of a black body radiating the same amt. per cm^2 per sec.

Radn of a black body is = σT^4

$\sigma = 5.70\ 10^{-5}$ ergs/sec degrees^{-4} cm^{-2}

Coblentz's determination

Bureau of Standards

From Quantum Thy same value.

Radius of sun $7\ 10^{10}$ cm.

Av. distance $1.5\ 10^{13}$.

σ (in cals. min^{-1} cm^{-2}) $= 8.19\ 10^{-11}$

∴ Energy at Surface of Sun $= \dfrac{1.94 \times 1.5^2 \times 10^{26}}{7^2\ 10^{20}} = 8.19\ 10^{-11}\ T^4$

Hence $T = 5740°$

This is meaningless if sun is not radiating like a black body. This is only partially justified but evidently 6000 is the order.

This is limited to regions near surface since temp gradient is prob. fairly high.

Boiling pts.
Crit. temps } < 6000°

∴ those parts of the sun wh. we can see i.e. within opacity limits are entirely gaseous – no condensation clouds.

Hence as interior can only be hotter the gaseous argument runs in to centre. i.e. whole sun in gaseous state.

Old theories were based on earth analogy. Sun spots were holes thro ~~dark~~ incandescent clouds to dark interior.

Photosphere – that sphere which agrees with the apparent form of the sun. (probably no clear edge surface but a gradual grading off. Pure gravitational theory wd. call for an even sharper edge than is observed.

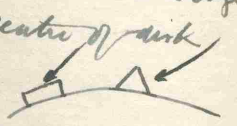
Solar réseau or rice grain or pores. patches of light particles & dark patch at surface.

Limb is the apparant edge of the sun.
ratio of intensity of spectral lines

Darkening of sun towards limb

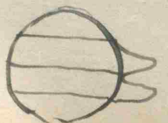
Thus analogy of sun to b.b. breaks down thus since a true b.b. emits or absorbs equally in all dirns
sun emits 3 times more radially than tangentially.

Sunspots discovered about 1600 by Galileo and Fabricius.
1st idea little planets passing across disk dark side towards earth.
Later change of vel near limb
+ of size noted i.e. foreshortening
Umbra + penumbra often a tongue of latter projecting into former.
Faculae bright spots on disk - often near sunspots - look like elevations above average surface + are not vis at centre of disk but near edge of disk due probably to having an irregular outline pyramidal - not table mountain



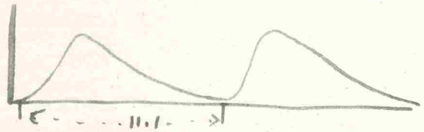
Sunspots:
(1) Confined to equatorial regions
never found outside ± 40°
(2) very rarely exactly on or very close to Solar equator.
i.e. not within ± 6° as a rule -

Graph of frequency in lat.

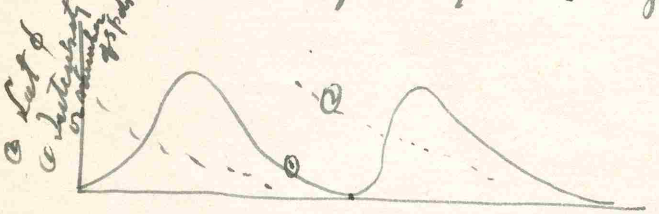


(3) Periodicity - 11.1 years.
Found by - **Schwabe** 1843 from observations 1820 - 1840. 2 cycles -

Graph of intensity



periodic, but steeper ascent, and period not always regular - 9 to 13 yrs.
Wolf of Zurich invented method of recording sunspots - Wolf's Sun Spot numbers.
no. of spots weighted by areas + group -



Mean latitude steadily decreases. along cycle.

Spören

Spots are often in groups + very often in pairs one preceding other.

Carrington 1860-1860 Took times of transit + found (1) Sun's axis inclined 7° to Ecliptic
(2) Period at equator 25.2 days.
(3) Period increased with latitude.
at lat. 45° period is 27½ ~~degrees~~ days.

Empirical formula $\dot{\xi} = a + b\cos^2\phi$

$\xi = 11.3^\circ + 3.1^\circ \cos^2\phi$. gives diurnal motion at lat. ϕ.

Thus sun does not rotate like a rigid body

Circumferential vel. at equator 2 km/sec.

Ratio $\dfrac{\text{Centrifugal force at eq.}}{\text{gravity}} = \dfrac{\omega^2 r}{\text{"}g\text{"}}$

$= \dfrac{7 \cdot 10^{10}}{27.6 \times 981} \left(\dfrac{2\pi}{25 \times 24 \times 60 \times 60}\right)$

$= 2 \times 10^{-5}$

Practically inappreciable.

Accompanying sun spot intensity: magnetic storms, aurora, meteorological reports - wind, price of corn etc. all indicate some connection.

Eclipse phenomena.

1842 Total. (1) film of thin crimson light ~~—~~ Prominences & Protuberances.

corona close round.
Chromosphere extending far out.

1860. Kirchoff - Dark lines in solar spectrum.

Separation of solar lines + telluric lines latter are due to absorption in earth's atmosphere - due principally to O also to. O_3 CO_2 H_2O.

As sun nears horizon telluric lines strengthen - hence can be separated out.

Elements found in Sun (Photosphere)

Ca (K lines very strong) Fe many H_2 Na Mg

Co Si Al Ti Cr. Sc —— Ba C in various Combinatns.

Noticeable omissions.

No K. O N practically no He. though see later it is present.

Spectrum of Sun spots

is repetition of above but with different intensities.

"Arc" lines mostly strengthened
"Spark" " " weakened

Generally arc lines correspond to ~~higher~~ temp
∴ Sun spots have lower temp than photosphere generally.

Flutings due to TiO_2 MgH_2 CaH_2

Arcturus very like sunspot spectrum. (G)
(reddish.)

Capella " " sun (yellow)
chromosphere (A.)
"Reversing" layer (deeper) (F)

29/1/23.

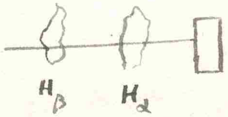
No. data on abs. radiation from a sunspot but it is known to be less than its surroundings + appears black only by contrast.

1868 Janssen + Lockyer Observed Eclipse.
(Java)
saw spectrum of prominence
H. yellow line supposed to be Na
J. thought it was so bright he should see it next day (no eclipse) + did so. using a slit. (no prom. vis. to naked eye)

H. prominence (Hα red monochromatic line remains fine even if dispersion is high
Diffuse skylight weakened by large dispersion
Continuous background in the region of H_α weakened until monochromatic H_α shows up by contrast

Thus both J. + L. observed prominences by daylight. J. since by eclipse it was so bright. L by above argument.
J. saw it first but the achievements were made public simultaneously at Paris Acad.

Slit gives monochromatic narrow sections
Move slit over prominence + reconstruct by addition of the sections.
Oscillating slit not a success.
Next attempt with a broad slit
getting whole prominence

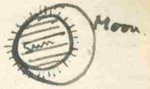


[Picture in Secchi's Book.]

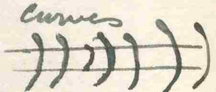
1869 Young - visual obsn. Spectrum of Corona.
Continuous spect with faint Fraunr. lines superimposed on it a bright line spec.
λ5303 (green) unknown origin.
[Lockyers D_3 line was not Na but is He. D_3 5875 whereas D_2 5890 D_1 5896 are Na.
the above green line is called Coronium.
not yet obtained artificially.
it is strongest out from sun's edge.
With prism in slit get overlapping rings most conspicuous being this green line.

1871 Young: Flash spectrum
Total eclipse when moon's ang. diam. > sun's
At instant of 2nd contact
moon's limb has internal contact with sun's limb.

The portion of sun's atmosphere then exposed is a crescent



Examined with spectroscope without slit
crescent fine & acts as its own (curved) slit
Spectrum consists of a no. of curves



Bright line spectrum showing almost every line bright wh. is a dark Fraun. line - i.e. reversed Fr. spectrum
Sudden change from Fr. sp. to the above at instant of contact - with D_3 very bright
As moon passes on one line after another goes out last remaining being due to light gases furthest out.

Flash spectrum differs from Fr. Sp.
(1) rel. intensities very diff.
(2) Arcs (constituting the lines) are of very unequal lengths.
These imply that the gases respons. for the diff. radiations must extend to very diff. heights.
Position of tips of crescents give relative heights to wh. the gas extends.
tips have been exposed longer & are ∴ more intense than central portions of crescents.

Mitchell : Astrophys J. 1913. vol. 38 p. 407.
Best photos of Flash sp. with heights worked out.

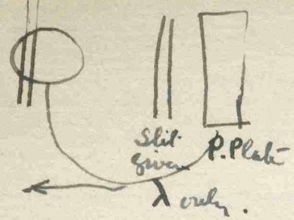
Ca$^+$ K ^{3933} H ^{3968} 14000 Km (1π-1S)
Ca 4227 (1S-1P) 5000 Km
Notation in Fowler's Report on Line spectra.

H δ
H γ 8000 Kms.
H β
(31 lines of Balmer series observed.)

He Doublets (ortho He) 6000 - 7000 Km.
Singlets (parhelium) 1000 - 1500 "
He$^+$ 4686 2000 Km.

Sr$^+$ 6000
Na D 1000
Mg b group in green 1000 (1p-1s)
triplet about 3840 6000-7000 (1p-2d)
Mg$^+$ 4481 400 (2δ-3φ)

1892 Hale (USA) Deslandres (Paris) Photographed whole set of prominences simultaneously
Took 1 line only & moved round entire disk of sun.



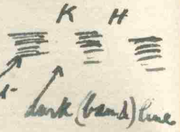
Spectroheliograph
giving a Spectroheliogram
(monochromatic.
distinguish photoheliogram
(not monochrom)

Easier to move slits + mirrors + keep P.P. +
Solar image fixed.

This method used for examining disk of sun
SpHeliogram of sun shows white patches called
Flocculi. (distinguish from Faculae.)

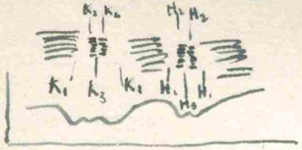
31/1/23 Ca lines

Ordinary solar spectrum fair dispersion



gtr dispersion

still gtr



Intensity graph.

centres very fine compared to wing.

governing factors are Breadth of slit
Posn. " "

Broad slit in centre usually covers whole of centre portion + is called K_{232}

Narrow slit can be set on any line K_2, K_2, K_3.

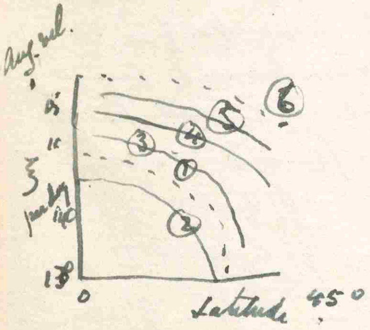
Photospheric background.

Possibly { Reversing layer of cooler Ca giving K_1 K_1
Above this a layer of less dense Ca " K_2 K_2
" " " " " " " Ca " K_3

Explanation of above not yet certain.

Cambridge spectroheliograms are in K_{232} light
Paris K_3, K_2
Mt Wilson K_3, K_2 + H_α (red)

Plates taken with these diff. lines represent diff. levels –



Solar rotation measured by
(1) Motion of partic. features across disc.
(2) Spect.c method – Doppler effect betw. E + W. limb.

(1) Make use of Sunspots, flocculi, faculae dark prominences
(2) Try diff. lines.

② From most ordinary Fr. lines Reversing layer.
① Sunspots.
③ Flocculi Ca + Faculae.
④ 4227 Ca.
⑤ H_α
⑥ Ca K_3 + K_3.

Consider diff heights in Chromosphere

Order of increasing ang. vel. and ~~with~~ decreasing equatorial accel. is order of heights in chromosphere spectrum.
Also order suggested by consideration of level in the spectroheliograms.

Hale saw motion of H filament into sunspot + calculated prob. vel. 100 km/sec.
∴ vortex movement accompanied by mag. + el. mag fields ∴ look for Zeeman effect. He found 2 components circularly polarized in opp dirns. Hence he inferred the source of light situated in a mag field lines of force ∥ to line of sight

This was noted in certain lines of Fe. Ti. Cr. (fainter lines – intense lines did not show it.

Used ¼ wave plate + Nicol prism. changing. ⊙ly polarized light into plane pol. detected by nicol.

1500-3000 gauss is measure of field (cf. earth's field about 0.2 gauss)

Difficulties (1) sometimes 3 lines
(2) diff. lines gave diff. fields.

---

(3) intensest lines no field

∴ Assume rapid decrease in field above solar surface.

Hence infer levels of those lines not previously known. Assume faint lines in general come from great depth. + region of grt mag. field intensity.

Next stage in argument
(1) Mag. field
(2) Dirn.
(3) Sense
(4) If we can find rotation direction of moving charge causing field we can tell whether charge ±.
It came out –ve Assuming rotation from Hα vortices.

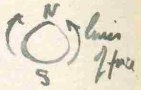
Hale's paper Ap. J. 28. 315. 1908.
" " 49. 153. 1919.
(after 11 yr cycle)

Directions of rotation had not changed.

but predominant polarity had changed.

Many difficulties regarding motion + rotation suggested vortex explanation.

Hale 1913. obtained general mag. field of
Sun 50 gauss.
Mag. axis ∥ˡ geog. axis approx
Polarity same as earth's
Layer 500 km. thick



Mag. axis slightly inclined to rotational axis.

5/2/23. Mass of gas - non uniform rotation.
. Compressible or uncompres.

p = pres. at any pt in interior (xyz)
ρ = dens. ω = ang. vel. of rotation.
V = gravit. or other potential
Eqⁿˢ of relative equilib with centrifugal force

$$-\frac{\partial p}{\partial x}+\rho\frac{\partial V}{\partial x}=-\omega^2\rho . x$$
$$-\frac{\partial p}{\partial y}+\rho\frac{\partial V}{\partial y}=-\omega^2 . \rho . y$$
$$-\frac{\partial p}{\partial z}+\rho\frac{\partial V}{\partial y}=~~-\omega\rho . z~~\ 0$$

where Oz axis is axis of rotation.

$$-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\partial V}{dx}=-\omega^2 x \quad ①$$
$$-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\partial V}{\partial y}=-\omega^2 y \quad ②$$
$$-\frac{1}{\rho}\frac{\partial p}{\partial z}+\frac{\partial V}{\partial z}=0 \quad ③$$

diff. ① w. ref. to y
② " " " x & subtract

$$\frac{1}{\rho^2}\left[\frac{\partial \rho}{\partial x}\frac{\partial p}{\partial y}-\frac{\partial p}{\partial y}\cdot\frac{\partial \rho}{\partial x}\right]=-x\frac{\partial \omega^2}{\partial y}+y\frac{\partial \omega^2}{\partial x}$$

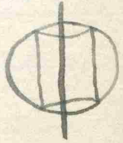
Assume $p = f(\rho)$ i.e. pts at same dens. have same pres.

Jacobi. $$\frac{\partial(p\rho)}{\partial(xy)}\equiv\frac{\partial p}{\partial x}\frac{\partial \rho}{\partial y}-\frac{\partial p}{\partial y}\frac{\partial \rho}{\partial x}=0$$

$$\therefore -x\frac{\partial \omega^2}{\partial y}+y\frac{\partial \omega^2}{\partial x}=0$$

$$\frac{\frac{\partial \omega^2}{\partial x}}{\frac{\partial(x^2+y^2)}{\partial x}}=\frac{\frac{\partial \omega^2}{\partial y}}{\frac{\partial(x^2+y^2)}{\partial y}}=\frac{\frac{\partial \omega^2}{\partial z}}{0}=\frac{\frac{\partial \omega^2}{\partial z}}{\frac{\partial(x^2+y^2)}{\partial z}}$$

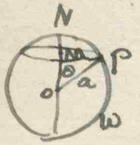
Hence ω^2 is function of x^2+y^2 only.
& is indep.ᵗ of z.
∴ surfaces of constant angular vel are cylinders about axis of rotation.



This neglects radiation pressure but even including it probably similar result.

If contraction I = moment of inertia.
$I\omega$ const.
I decreases as ω increases
∴ equatorial regions have gt.ˢᵗ velocity.

Impos. of a free charge on solar surface of sufficient magnitude to give by its rotation the observed solar mag. field



Consider uniformly charged sphere.
surface dens. σ
In co-lat. θ linear vel.
is $a\omega\sin\theta$.

$\therefore$ Current in ~~thin~~ strip $(\theta, \theta + d\theta)$
is $a\omega\sin\theta \cdot \sigma a\, d\theta$ E.S.U.
= charge passing a given pt per second.

In EMU. cur $C = \dfrac{\sigma a^2 \omega \sin\theta . d\theta}{c}$

Intensity at N.

Intens. due to C at θ is $\dfrac{2\pi (PM)^2}{(PN)^3} C$

$$= \frac{2\pi (a\sin\theta)^2 C}{(2a\sin\frac{\theta}{2})^3}$$

$$= \frac{\sigma}{c} \frac{2\pi a \omega}{4} \frac{\sin^3\theta\, d\theta}{\sin^2\frac{\theta}{2}}$$

Hence total intens at N by integration.

$$\frac{\sigma\pi a \omega}{2c} \times 8 \int_0^\pi \sin\frac{\theta}{2} \cos^3\frac{\theta}{2}\, d\theta .$$

$$= \frac{2\pi a \omega \sigma}{c} = H \text{ gauss.}$$

Pot^l in ESU. $= \dfrac{4\pi a^2\sigma}{a} = 4\pi a \sigma$

If V is pot. in volts

$$V = 4\pi a\sigma \frac{c}{10^8}$$

$$\therefore V = \frac{2c^2 H}{10^8 \omega}$$

at sun according to Hale

$H = 50$ gauss. ~~$\omega = 2\pi$~~ $\omega = \dfrac{2\pi}{30 \times 24 \times 60^2}$

$\therefore V = 4 \times 10^{20}$ wh. is impos.

for earth it comes out 5×10^{16}
wh. is also impos.

Earths mag. cannot produce the surface charge existing.

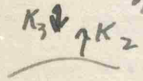
Motion of Ca vapour over whole Sun (1910)

1. Ca vapour producing K_3 (dark absorption line) has a descending motion over general surface of sun of about 1.1 km per sec. (shift to red from limb inwards)
2. Ca vap. K_2 ascending motion 2.0 km per sec. (shift to violet)
3. K_3 vap. probably const ang. vel. up to lat ±40 $15\frac{1}{2}$°.0 per day.
4. Pres. in layer in wh. K_1 + K_3 originate order of 1 atmos
(this conclusion prob. wrong - other explan)

5. no current ∥^l to solar s

6. Height of chromosphere - without eclipse.
5000 Km. Ca.
K_3 K_2 densities very small.
Increase of width from centre to limb

This explanation does not seem sufficient



no balance.

Consider agitation of Ca atoms at 5000 deg.

$$\tfrac{1}{2} mv^2 = \tfrac{3}{2} RT.$$

$$v = \sqrt{\frac{3R}{mT}} \simeq 1.76 \text{ Km/sec}.$$

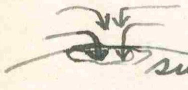
They are emitting as they go up & absorb as they fall.
but erratic motion thus assumed cannot explain the phenom.
Convection currents not sufficient.

1910 Evershed said he detected radial motion in sunspots.

1911. St John confirmed it for Ca motion
1 Majority of spots. Ca vap$^{(K_2)}$ is descending into umbra with vel. 1.7 to 2.2 Km/sec

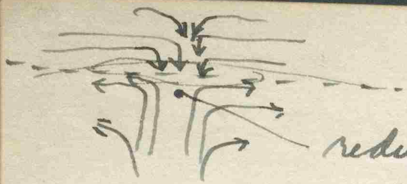
K Ca line is brightly reversed.
2. Penumbra Ca (K_2) has very little vertical motion.
3. Flocculi possibly a little upward motion.

for Radial motion Ca vap. moves inwards across penumbrae.
bigger speed for K_3 than for K_2
very occasionally a rotary motion.



vap. comes in horizontally & is sucked down.

1913. Repeated obs^ns for all line Motion in Sunspots.
1. Confirmed Evershed
Movement tangential to Solar Surface
i.e. radial to axis of sun spot.
2. Chromosphere. flow inward
Reversing layer - " outward
3. Intensity of a given Fe. line in the reversing layer get fainter radial motion, outward more pronounced.
In Chromosphere the higher the level the more pronounced the inward motion
see diagram



Vortex motion

reduction of pres where
vel. is highest.

H lines up high showing vortex motion.
at - - - - zero vel. level no " "
in lower Ca vortex it appears again.

St John used this method to get levels of ther lines - eg. Fe.
Faintest lines gave gtst speed.
thus he formed an arbitrary Fe Scale of levels, intensities & speeds -
& compared lines of 26 other elements.
This scale was corroborated by height of $H\alpha$ K_3, by spectroscopic determination of vels. & by mag. intensity results.

St. Johns Scale.
Order of decreasing heights.

Ca	H	Mg	Na	Fe	Sr	Ti	Cr	Mn	Co	Ba	CN	Zr
40	1	24	23	56	57	48		55		137	28	rare earths

There is only a partial correlation with atomic wt.

7/2/23 (copied from C.P.)

Pressure in solar atmosphere
Usually detected & measured by pressure shift.
(Doppler shift $\propto \lambda$, Pressure shift does not)
Difficulty very gt.
Humphreys + Mohler 1 - 10 atmos in reversing layer.
Fabry & Buisson 1910 Interferiometer measures
(1) 4 - 5 atmos (2) 1 atmos.
Journal de Physique Apr. 1922. Perot. Interferometer.
Consider 2 wave lengths λ_1 λ_2 from same level.
$\frac{\lambda_1}{\lambda_2}$ unaltered by Doppler Effect + Einstein Effect.

$$\delta\lambda_1 = \text{pressure coef.} \times \text{pressure} = k_1 p_1$$
$$\delta\lambda_2 = \qquad k_2 p_2$$
$$\therefore \frac{\lambda_1 + k_1 p_1}{\lambda_2 + k_2 p_2} = \frac{\lambda_1}{\lambda_2}\left\{1 + p_1\left(\frac{k_1}{\lambda_1} - \frac{k_2}{\lambda_2}\right)\right\}$$

If $k_1 \neq k_2$ and not $\propto \lambda$ this will discriminate pressure & other effects.
Suitable pair is given by Mg. b. 5180.
Does not depend on absolute determination of λ
Einstein effect ·011 Å observed ·013 Å
But shift for 1 atmos. pres. = ·006 Å
" " rise of Mg = ·007 Å (doubtful)

Result : 30 cm Hg.
The more accurate the determinations, the smaller the observed pressures.

Convection in Solar Atmosphere.

1903 Ap. J. 13. 173.

Energy per cm^2 per sec. $= 6.2\ 10^{10}$ ergs.

Energy $\frac{3}{2}RT$ per mol. $= \frac{p}{\rho}\,\frac{R}{m}\,T$

Energy $= \frac{3}{2}p$ per unit vol.

$p = 10^6$ dynes energy loss per sec.

$=$ energy in layer of thickness $\frac{6.2\ 10^{10}}{\frac{3}{2}\ 10^6} = 4\ 10^4$ c

Assume. Gas rushes to surface with vel. v
— cools — reduction of pres by 1 atmos —
then descends again!

Then $v = 400$ metres/sec $= 0.4$ km/sec.
Schuster's value was 0.6 km/sec.
There cannot be a convective gradient since if there were we shd. get a far gtr darkening at the limb.
The gradient is radiative & not convective & it $\propto T^4$ which is a linear function of the optical depth $\tau = \int_0^x k\rho\,dx$

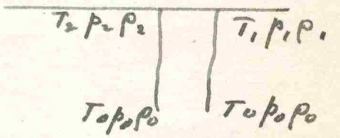
Under gravitational equilibrium $p = \int_0^x g\rho\,dx$

$\therefore \frac{\tau}{p} = \frac{k}{g}$.

$T^4 \propto p$ gives temp gradient in Radiative Equilibrium.

Sunspots.

Plausible to suppose a sudden uprush of gases from below. Attribute low t° of umbra to cooling by adiabatic expansion.
We assume that the (known) cooling is entirely produced by adiabatic expansion due to rise from the appropriate level (at same temp as photosphere)



H N Russell 1921.
Radiative gradient
$T^4 \propto p$
$\rho \propto \frac{p}{T} \propto T^3$
Adiabatic gradient
$T \propto \rho^{\gamma-1} \propto p^{\frac{\gamma-1}{\gamma}}$

At the ~~top~~ assume pressure equalizes itself — $p_2 = p_1$

then $\rho_2 T_2 = \rho_1 T_1$

But $\frac{T_1^4}{T_0^4} = \frac{p_1}{p_0}$ & $\frac{T_2^{\frac{\gamma}{\gamma-1}}}{T_0^{\frac{\gamma}{\gamma-1}}} = \frac{p_2}{p_0} = \frac{p_1}{p_0}$

$\therefore \frac{T_1^4}{T_0^4} = \frac{T_2^{\frac{\gamma}{\gamma-1}}}{T_0^{\frac{\gamma}{\gamma-1}}}$ $\therefore T_0^{\frac{\gamma}{\gamma-1}-4} = \frac{T_2^{\frac{\gamma}{\gamma-1}}}{T_1^4}$

$\frac{T_0}{T_1} = \left(\frac{T_1}{T_2}\right)^{\frac{\gamma}{3\gamma-4}}$

Since $\frac{p_0}{p_1} = \left(\frac{T_0}{T_1}\right)^4$ $\frac{\rho_0}{\rho_1} = \left(\frac{T_0}{T_1}\right)^3$

At these temps. all gases are monatomic
$T_1 = 6000°$
$\gamma = 5/3$ $\frac{T_1}{T_2} = 1.5$
$\therefore T_0 = 2.0\,T_1 = 12000°$ and $p_0 = 16 p_1$
$\rho_0 = 8\rho_1 = 5{\cdot}3\,\rho$

This is clearly an underestimate since
1/ adiabatic cooling wd. give the gtst possible cooling & we have not allowed for radiation
2/ TiO_2 etc are exothermic
3/ Neutralization of ions.
Thus actual depth must be greater.
If we take γ as for a diatomic gas = 1.4

$T_0 = 17\,T_1 = 100\,000°$

$p_0 = 80\,000\,p_1$

$\rho_0 = 5\,000\,\rho_1 = 3300\,\rho_2$.

If we assume sunspots dark by convective cooling ex hypothesi there can be no convective gradient beneath the photosphere.

Equilibrium of the Chromosphere

Isothermal Atmosphere. $\frac{p}{p_0} = e^{-mgx/RT}$.
Gravitational equilib only.
x = height above reference level where pres = p_0
for Sun $g = 2.7\ 10^4$
For atomic H. $\frac{R}{m} = 8.26\ 10^7$
for x = 1000 km. = 10^8 cm

$\frac{p}{p_0}$ (atomic H) $= e^{-5.4} = 10^{-2.35}$

for x = 5000 km

$\frac{p}{p_0} = 10^{-11.7}$

for x = 8000 km (height of flash spectrum from eclipse

$\frac{p}{p_0} = 10^{-18.7}$

For Ca.

$x = 5000$ km $\frac{p}{p_0} = 10^{-468}$ an absurd value.

Mitchell observes Ca at 15000 km.
Still worse for prominences which cannot be supported even for H.

Radiation Pressure

M.N. R.A.S. Vol. 80. p. 723. 1920 Eddington
Emission 6.2 10^{10} ergs/cm²sec.
Corresponding radn pres. $= \frac{6.2\ 10^{10}}{3\ 10^{10}} = 2$ dynes/cm²
This is all the r.p. wh. could be caused by all the radn reaching us if completely absorbed.
But half is re emitted backwards.
Thus we really have 4 dynes/cm².
If photosphere T° 12 000 instead of 6000° then r.p = 64 dynes/cm²
$g = 2.7\ 10^4$
approx $3\ 10^4$
approx. 30 dynes/cm²

∴ Mass supported $= \frac{p}{g} = 1$ mg/cm².
This is an absolute upper limit to the amount of matter wh. can be supported.

For a prominence height 10.000 km emitting line H_α &c
we get 10^{-12} for mean density

A totally different calcn. based on obsns in flames also gives 10^{-12}.

Infer that molecular scattering gives no effect i.e. Sun has no "sky".

12/2/23.

Quantum Theory

Calcium K line. λ 3933

Quantum $h\nu$ absorbed corresponds to momentum communicated $\frac{h\nu}{c} = \frac{h}{\lambda}$

Momentum per quantum $\frac{6.55\ 10^{-17}}{3.933\ 10^{-5}}$

Mass of Ca atom $40 \times 1.64\ 10^{-14}$

∴ increment of vel = quotient of above = 2.54 cm sec^{-1}

"g" on Sun 0.27 km sec^{-2} = 2.7 10^4 cm sec^{-2}

$\frac{2.7 \times 10^4}{2.54} = 10^4$

= rate of absorption neces. if the atom is to stay at surface.

no change of momentum due to the radiation.

The ~~energy per sec~~ intensity (Plancks formula) emitted $(\lambda, \lambda + d\lambda)$ at temp T is $\frac{2hc^2\lambda^{-5}}{e^{hc/\lambda RT} - 1}\, d\lambda$

Ⓐ

Monochromatic absorption or emission not literally monochromatic & harmonic else change of picking up energy wd. be infinitely small – Consider a small region about λ

A totally different calc^n based on obs^{ns} in flames also gives 10^{-12}.

Infer that molecular scattering gives no effect i.e. sun has no "sky".

12/2/23.

∴ work out an upper limit for rad^n pres—

Take $d\lambda = 5$ Å   Doppler effect being 3.80 Km/sec.

$R = 1.37 \; 10^{-16}$ $hc/R = 1.4325$

$T = 5000$

Then A has value 4.26×10^6 energy per sec per unit solid angle per unit area from photosphere

No. of quanta ~~maintaining~~ contained in this ~~of~~ amt. $h\nu = 0.85 \; 10^{18}$

Mass of Ca atom $40 \times 1.64 \; 10^{-24}$ gms has to absorb $1.06 \; 10^4$ quanta per sec.

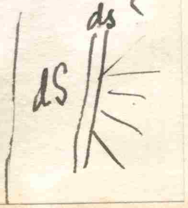
∴ Equiv. mass absorption coeff. (by def^n a fraction of the incident radiation absorbed per unit mass per sec.)

$$= \frac{1.06 \times 10^4}{0.85 \; 10^{18} \pi \; 40 \times 1.64 \, 10^{-24}} = 0.6 \; 10^8$$

$\delta I = k \rho I \, ds$ ds is short stretch of path in wh. intensity I is reduced by δI

∴ energy absorbed $= k\rho \, ds \, dS \iint I \cos\theta \, d\omega = \pi I k . dm$

$$\therefore k = \delta I / \pi I \, dm$$



This absorption coeff. is very high. as compared with X. ray absorption &c.
i.e. path in wh. radiation is reduced to ½ value is very small –

Photosphere radⁿ in $d\lambda$ is $4.26\ 10^6$ erg./sec.
∴ pressure arising from this is. $\frac{4.26\ 10^6}{3 \cdot 10^{10}} = 1.42\ 10^{-4}$.
$g = 2.7\ 10^4$ pressure $p = mg$ m = mass supported.
$m = \frac{1.42\ 10^{-4}}{2.7\ 10^4} = 5.25\ 10^{-9}$ gms – per unit area.

Take a column of chromosphere & work out total mass of Ca. supported & this gives the mass per unit area.

for higher temps still $k = 2 \times 10^8$

Consider ~~temp~~ height 5000 km & 10^{-4} atmosphere
radiation pressure cannot support.

5000 Km in grav eq. Ca $\quad p/p_0 = 10^{-4}$ atmos

$p = 10^{-11}$ atmos $\quad p_0 = 10^{+4}$

$$\rho\, l = \frac{p\, m}{RT}\, l = 5 \text{ gms.}$$

Max$^{\underline{m}}$ mass ~~pressure~~ of rad. pres. supports it was seen to be $5\ 10^{-9}$ gms.
then the pres. must be 10^{-9} times smaller than in the Saha estimate.
i.e. pres. of order 10^{-13} atmos.

Calc. no. of collisions per sec. at this pres. suffered by a single mol. $\quad \sqrt{2}\,\pi\,\nu\,\sigma^2\,\bar{c}$

at above pres. & temp 5000

$\nu = 1.5\ 10^{5}$ mols/cc.

& $\bar{c} = 1.75\ 10^{-5}$ $\quad$ (2 Km/sec for Ca mol)

$\sigma = 5\ 10^{-8}$

ν = no. of mols per cc,
σ = mol. diam
$\bar{c}$ = mean speed.

Then number of collisions $= 3\ 10^{-4}$ per sec.
i.e. practically no collisions.

5000 L

i.e. mols floating independently under rad^n pressure. Some rising & some falling according to amt. of radiation absorbed or lost.

Stark & Wood on time req^d. to absorb to saturation 10^{-4} to 10^{-7} sec.

In above we have got rid of pres. gradient but omitted rad^n press intensity gradient.

Ionization

Ref. Etherial Ionization.

M N. **Saha** Phil Mag. 40. 472. Oct. 1920.
40. 809. Dec 1920.
41. 267. Feb. 1921.
Proc. R.S. 99 A. 1128. 1921.
Zeits fur Phys. Bd. VI 40. 1921.

} Based on Nernsts' Theory & Phys. Chem.

SAHA

14/2/23 Reaction $X \rightleftarrows Y+Z$

Elementary account in Observatory. Sept. 1921.

Flame lines
Arc. lines
Spark lines

Lockyer first found "enhanced" lines.
strong in spark relative to arc.
found in Fe, Ti, Si &c.
λ 4481 strong in Mg spark.
not pres. " Mg arc.

∴ Lockyer said temps of stars could be deduced from presence of these lines in certain stars.

Understood now by series. Arc. line constant N.
4 N suggested by Bohr Spark " " 4 N.

A. Fowler (S. Kens) put Ca. Sr, Mg, Ba into groups & found these series.

Thus shown that enhanced lines due to ionized atoms
& ordinary arc " " " normal neutral atom.

Sommerfelt (Kossel) periodic table & lines. Potassium & enhanced Ca have qualitatively similar spectra

K | Ca
 | Ca_+

14/2/33. Reaction $X \rightleftarrows Y + Z$

1 mol. 2 mols.

Explanⁿ of presence of enhanced lines in Star.
Ionization by photoel.-effect of the gas itself at high temps.

Thermodynamic formula applied by Eggert first but until Saha no one realized the full significance
Law of mass action & other Phys.-Chem phenom.
applies to the reaction $Ca \rightleftarrows Ca^+ + e - U$
Where e = 1 electron & U = energy term = work reqᵈ.
to withdraw the el- & work released by restoring it.
free electrons behave as a monatomic gas.
& the Ca ion has practically same mass as the Ca atom.

$$\frac{\quad}{p} = K_p = KRT$$

14/2/23. Reaction $X \rightleftarrows Y + Z$

1 mol. 2 mols.

Tendancy to decompose at any temp + pres.
Steady State.

Mol. concentration of X : c
" " " Y : c_1
Z : c_2

No. of mols of X decomposing per sec $\propto$ no present.

$\therefore$ vel. $\rightarrow$ $\propto kc$
vel $\leftarrow$ $\propto$ chance of Y encountering Z
$\propto k' c_1 c_2$

In Equilib. $kc = k' c_1 c_2$

$$\frac{c_1 c_2}{c} = K$$

This is Law of Mass Action.
(Kinetic Thy for Law of mass action acc. to Lewis' Phys Chem)

K a function of T not of p.

Work in pres. rather than concentns.
put $p = cRT$ c = no of mols in 1 gm. mol.

Then $$\frac{p_1 p_2}{p} = K_p = KRT$$

P = total pres.

x = fraction of mols wh. are ionized.

no. of ptcls is $(1-x)_X + (x)_Y + (x)_Z$

$$p = \frac{1-x}{1+x} P$$

$$p_1 = \frac{x}{1+x} P$$

$$p_2 = \frac{x}{1+x} P.$$

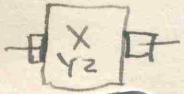
$$K_p = \frac{x^2}{1-x^2} P$$

$$X \rightleftarrows Y + Z - U$$

U = energy to decompose 1 mol X.
absorbed – constant vol.

Thermodynamic cycle

Take a ~~quantity of X~~ chamber at temp T



fitted with semi permeable membranes so that one or other can be drawn off.
Van't Hoff Equilibrium box.

2 boxes. T. C. $c_1\ c_2$ ∴
C' $c_1'\ c_2'$

Withdraw 1 gm. mol. of X at const pres. from T

External work performed is $p_{\cancel{x}} v_{\cancel{x}} = RT$.

Compress isothermally till concentration C' is attained & partial pres. p'

work done on the gas $= \int p\,dv = RT\int\frac{dv}{v} = RT\log\frac{p'}{p}$

Compress it thro membrane into other box
work done is $p'v' = RT$
cancels external work done

withdraw from ② Y + Z separately & compress by partial pres. $p_1'\ p_2'$

Expand these isothermally down to $p_1\ p_2$ & redeliver them into box ①.

work done again cancels.

2 terms left. $RT\log\frac{p_1'}{p_2'}$ $RT\log\frac{p_2'}{p_2}$
work gained work done

Isothermal ∴ no loss of ~~work~~ energy.

$$\therefore \log\frac{P}{p'} = \log\frac{p_1'}{p_1} = \log\frac{p_2'}{p_2}$$

or $\frac{p_1 p_2}{p} = \frac{p_1' p_2'}{p'} = K_p$

& this is law of mass action in other form.

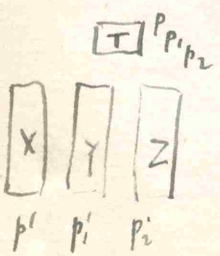
---

2 Boxes at T & T+dT

1. withdraw X from 1.
2. Warm up, const vol. to T+dT.
3. Alter pres. isothermally till equilib.
4. Deliver to box ②.
5. withdraw
6. Cool at const vol.
7. Expand isothermally
8. Redeliver to ①

Equate work done & gained
This is from 1st principles.

Use this method.



Possible to withdraw from large X Y Z without altering concentrations appreciably.

$X \rightarrow Y + Z$.

work of delivery from X, Y Z into T & ~~reverse~~ expansion cancel each = RT.

The only work comes from the isothermal compression.

Work lost in sending mol X to box =
$RT \log \frac{p}{p'}$.
" gained in transferring Y, Z from box =
$RT \log \frac{p_1}{p_1'} + RT \log \frac{p_2}{p_2'}$.

$\therefore$ work gained $= RT\left\{\log \frac{p_1 p_2}{p} - \log \frac{p_1' p_2'}{p'}\right\}$
undashed symbols refer to equilib. values.

$\therefore \quad A = RT\left[\log K_p - \log \frac{p_1' p_2'}{p'}\right]$

dashed symbols are arbitrary.

Nernst & Lewis call this A (maximum work)

Thermodynamic formula for this is.

$A - U = T\left(\frac{dA}{dT}\right)_{\text{const vol.}}$ Helmholtz formula

U = decrease of energy in this process
= heat evolved at const vol.
A = max^m work " " "

Object is to get variation of K by getting 1st A into a differentiable form

Use $A = RT\left[\log K - \log \frac{c_1' c_2'}{c'}\right]$

arbitrary concentrations.

Insert in other & diff.

$$RT\log K - RT\log\frac{c_1' c_2'}{c'} - U = T\frac{dA}{dT}$$

$$= T\left[R\log K - R\log\frac{c_1' c_2'}{c'} + RT\frac{d(\log K)}{dT}\right]$$

Cancel out common terms

$$-\frac{U}{RT^2} = \frac{d(\log K)}{dT}$$

Note K can be diffted at const vol. with regard to but not $\frac{c_1 c_2}{c'}$.

Note. Helmholtz

$\frac{dQ}{Q} = \frac{dT}{dT}$ where $dQ = dA$.

$Q = A - U$.

We had $K_p = KRT$

$$\frac{d(\log K_p)}{dT} = \frac{d\log K}{dT} + \frac{1}{T}dT.$$

$$= -\frac{U}{RT^2} + \frac{1}{T} = \frac{-U+RT}{RT^2}.$$

U is neg = heat absorbed.

write $-U$ for U.

Now U = heat reqd at const vol.

$$\frac{d(\log K_p)}{dt} = \frac{U+RT}{RT^2}$$

U is a function of temp since thermal capacities of products differ from those of constituents.

If γ γ_1 γ_2 are mol. spc. heats at const. vol.

Then $\frac{dU}{dT} = \gamma_1 + \gamma_2 - \gamma_1$.

Integrating $U = U_0 + (\gamma_1 + \gamma_2 - \gamma)T$.

for perfect gas $\gamma_1 = \gamma_2 = \gamma = \frac{3}{2}R$

$\therefore U = U_0 + \frac{3}{2}RT$.

$$\therefore \frac{d(\log K_p)}{dt} = \frac{U_0 + \frac{5}{2}RT}{RT^2}.$$

U_0 is here a const. indept of temp.

$\therefore$ Integrating $\log K_p = -\frac{U_0}{RT} + \frac{5}{2}\log T + \text{const}.$

This is the Saha formulae used for calculating degree of dissociation if const. be known.

$$\log \frac{x^2}{1-x^2} P = -\frac{U_0}{RT} + \frac{5}{2}\log T + \text{const.}$$

Hence find x.

Nernst heat theory – This const. is the algebraic sum of the consts in the corresponding vapour pressure formula. (See Lewis Phys. Chem. Roundabout proof)

Nernst Heat Thm depends on Entropy ideas.

$$S = Nk\left[\frac{5}{2}\log T - \log p + \log \frac{(2\pi m)^{3/2} k^{5/2}}{h^3}\right]$$

m = mass of mol.
h = Plancks const.

$X \rightarrow Y + Z$
$S \quad S_1 \quad S_2$ then $S_1 + S_2 - S = \frac{U_0}{T}$.

Put this in above & get the const = sum of things like $S =$ formula the Sackur – Tetrode formula.

[See Jan. Phil Mag Fowler
Based on Thy of Probabilities talking about

of the free energy KE, & the quantum energy – hence latter involves h

16/2/23.

See pages 1-5 inserted

19/2/23.

Reversing layer of Sun. temp 6000°.

~~Atmos~~ Pres. in atmos. % neutral atoms

Volts.	Element.	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-6}
4.16	Rb	37	12	1.2	0.2	0.002	
4.32	K	45	15	2	0.2	0.002	
5.11	Na	79	44	10	1.1	.011	
5.12	Ba	79		same			
9.86	Ba^+	11	55	90	98	48.	
6.08	Ca	96	84	31	7	.07	
11.86	Ca^+	4	16	59	93	98	84
13.524	H^+	2×10^{-6}	1×10^{-5}	8×10^{-5}	8×10^{-4}	0.08	

In a sunspot 4000°

Rb.	77	50	22	6	.09
K	84	61	31	9	.14
Ca	99.9	99.6	98.7	94.1	18.7

Note ordinary Periodic table

$$\begin{tikzcd} Li \arrow[r] \arrow[d] & Mg \\ Na & Ca \\ K \end{tikzcd}$$

Ioniz^n Ptl. increasing

Ioniz Ptl. decreasing.

Inserted at p. 46-47

16/2/23.

$$X \rightleftarrows Y + Z$$

$$\log K_p = \log \frac{x^2}{1-x^2} P = -\frac{U}{RT} + \frac{5}{2}\log T + \text{Const}.$$

$$\frac{x}{1-x^2} P = T^{\frac{3}{2}} e^{-\frac{U}{RT}} \times \text{Const}.$$

Const derived from Entropy considerations.
= Const for Y + for Z - Const for X.

Deriv^{n} of above by (1) Max^{m} Entropy
(2) Probable Energy distrib^{n}

Saha's fundamental idea
apply above to $Ca = Ca^+ + e$.

Hence a vapour of itself at high temp will become ionized.

Artificial ionization requires energy put in
natural ~~energy~~ ionization requires energy - uses its own heat
+ grows cooler.

Argument for $\frac{c_1 c_2}{c}$ = const from $kc = k'c_1 c_2$
seems to presuppose spontaneous action on left.
as opposed or balanced by action due to collisions on right.

$H_2O \rightleftarrows 2H + O$

$2H_2O \rightleftarrows 2H_2 + O_2$
(2) 2 + 1

Collisions with walls?
Radiation? action at low temp
offers difficulty.

Explanation by Perrin

Matière et lumière 1920 Annales de Physique.

Absorption of small quanta $h\nu$ of energy.

Not entirely satisfactory - not enough energy.

$\frac{p_1 p_2}{p}$

x = degree of ionization

$p = \frac{1-x}{1+x} P \quad p_1 = \frac{x}{1+x} P \quad p_2 = \frac{x}{1+x} P.$

$= \rightarrow \frac{x^2}{1-x^2} P.$ P decreases.

$\frac{x^2}{1-x^2}$ increases

$x \rightarrow 1.$

$\therefore$ Eq^n $kc^2 = k' c_1 c_2$ cannot hold rigorously.

but $\frac{c_1 c_2}{c}$ = const can be derived by other means.

Application to O type Stars. temp.

H atom 13.6 volts for ionization.

10. " " 2-quantum orbit (Resonance voltages)

1000 Å approx

Pressure cannot be neglected in these considerations.

$$\log_{10} \frac{x^2}{1-x^2} P = -\frac{5036\, I}{T} + \frac{5}{2} \log_{10} T - 6.5$$

P = in atmos.

I replaces U & is ionizing temp in volts.

Note that larger U

smaller is x.

larger T the nearer x approaches unity.

larger P smaller x.

3rd result was unexpected.

i.e. low pressures same result as high temps

i.e. give enhanced lines.

Ca. 6.08 volts. Table of x.

Pres. atmos.	10	~~10~~ 1	10^{-1}	10^{-2}	10^{-3}	10^{-4}
4000°	0	0	0	3	9	26
5	0	2	6	20	53	90
6	2	8	26	64	93	99
7	7	23	68	91	99	100
10	46	85	98.5	100	100	100
	%	%	%	%	%	%

Reversing layer of Sun - along row 6000.
Expect + find arc + spark lines both well developed.
Exact pres. uncertain.

In chromosphere pressure not 10^{-4}.
H K, Ca^+ 14000 km.
4237 line Ca 5000 "

Above table explains what had appeared as an inconsistency.

above 5000 km there are no 4237 line but there is Ca^+ hence ionization is complete.

New difficulty is why Ca 4237 goes as high as 5000 whereas previously it was why not as high as Ca^+ lines.

Similar Saha explanⁿ for Sr. + Ba.
Ionization voltage 5.7. 5.1.

4607 Sr. 350 Km.

4077
4216 Sr.$^+$ 6000 Km.

Na 5.1 volts ioniz. ptl.

D lines 5896
5890 1000 Kms.

All enhanced Na lines are in ultra violet
∴ no comparison possible.

K. 4.3 volts. (low)

K is almost completely ionized in reversing layer.
i.e. complete below an atmos. of 7000° $\frac{1}{10}$ atmos.

7699 (1s – 1π)
7664

4047
4044 (1s – 2π)

just enough atoms to give these lines
Cannot argue from this that less K than Na in Sun.

Mg 7.65 volts (high)
∴ not so much ionization.

triplet 3838 Mg 7000 Km.

4481 Mg$^+$ 400 Km. [not very strong in Sun but strong in some of the hotter stars & very strong in laboratory.
1st lines of main series are in ultra-violet
This one is (2S – 3d) first line)

He in Sun 25· volts Ioniz^{n}. pot. (Very high)
Saha theory does not account for observed phenom.
Trace of 4686 He^{+}
But no corresponding Fraunhofer line
$(1\sigma - mp)$ is really $(2\sigma - mp)$ since
former is in ultraviolet. Enhanced line is
$(2\delta - 3\phi)$ Amt of He is small ∴ not
enough atoms in 2σ state to give
absorption.
But enough in chromosphere to give
the flash lines when

See Plaskett's paper in Report of Dom. Ap. Obs. Vic. B.C.
Reviewed by A.E. Milne in Obs. for March.

Former in footnote refers to Russell's work on press.

Tho Na & Ba have same values in table
yet former has much stronger lines in spectrum.

Princ. series (1σ) line of a normal ionized atom strengthened in a sun spot
In a Subordinate series (say diffuse 1p–md)
But no of atoms in 1p state =
no of unionized atoms × fraction in 1p state
∴ uncertain whether strengthened or weakened – Generally found not strengthened as much as princ series.

Calculation

H. 1 quantum & 2 quantum orbits.
Treat change from 1 state to 2 state as a chem reaction requiring energy.
$X \rightleftarrows Y - U$ differs from $X \rightleftarrows Y + Z$
in that former has same no of mols before & after ∴ pressure unchanged.

Let x be fraction in state Y

$$\frac{x}{1-x}\frac{p}{p} = \frac{x}{1-x}$$

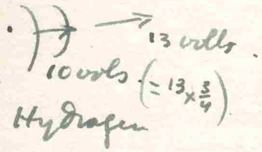
$$\log \frac{x}{1-x} = -\frac{U}{RT} + 0 + 0$$

i.e. no. in state 2 = no in state 1 × $e^{-\frac{h\nu}{RT}}$

$h\nu$ = energy req^d to raise electron to outer orbit.

See Fowlers paper in Phil. Mag.

For states other than steady state the fraction thus given is very small.



RT for a temp 10000
0.86 volts.

$$e^{-\frac{h\nu}{RT}} = e^{-\frac{10}{0.9}} = e^{-11}$$

Surprisingly small since lines of Balmer state are so great.

---

for He. lines from 2σ & 2S state are unaccountably strong.

2nd state ionization of Ca.

$Ca \rightarrow Ca^{+} + e$
$Ca^{+} \rightarrow Ca^{++} + e$

Let x = fraction of Ca once ionized
y = " " " twice "
p = total pressure.

no. of ptcls present

$$= (1-x-y) + \underset{Ca^+}{x} + \underset{Ca^{++}}{y} + \underset{e}{x+2y}$$

$$= 1 + x + 2y$$

$$\therefore \frac{1-x-y}{1+x+2y} P = \text{pres of Ca}$$

$$\frac{x}{1+x+2y} P \quad \text{for } Ca^+$$

$$\frac{y}{1+x+2y} P \quad \text{for } Ca^{++}$$

$$\frac{x+2y}{1+x+2y} P \quad \text{for } e.$$

Form constants

$$1. \quad K_1 = \frac{\frac{x}{1+x+2y} P \cdot \frac{x+2y}{1+x+2y} P}{\frac{1-x-y}{1+x+2y} P}$$

$$= \frac{x(x+2y)}{(1-x-y)(1+x+2y)} P$$

$$2. \quad K_2 = \frac{(x+2y)\,y}{(1+x+2y)\,x} = \text{Equilib. const for 2nd reaction.}$$

Thus 2 eqns for x + y & so calculate the 2 stages.

In stellar atmos. there are many free el. ∴ recombn takes place & ionizn less than is expected.

Russel. If several kinds of atoms $a_1\, a_2\, a_3$ — & fractions ionized. $x_1\, x_2\, x_3$.

Total no. of ptcls. $a_1 + a_1 x_1 +$ —

$$= \Sigma a_n (1 + x_n)$$

Hence for neutral atoms (of kind 1) If P be total pres. p_1 = partial pres.

$$p_1 = \frac{a_1(1-x_1)}{\Sigma a_n (1+x_n)} P.$$

Ionized. $p_1' = \frac{a_1 x_1}{\text{ditto}} P.$

Electrons $p'' = \frac{\Sigma a_n x_n}{\text{ditto}} P.$

Put $\bar{x} = \frac{\Sigma a_n x_n}{\Sigma a_n}$ = mean ionization

= fraction of all atoms ionized.

then $p'' = \frac{\bar{x}}{1+\bar{x}} P$.

∴ Equilib. constant K_1

$$K_1 = \frac{p_1' p''}{p_1} = \frac{x_1}{1-x_1} \cdot \frac{\bar{x}}{1+\bar{x}} P$$

(this replaces $\frac{x^2}{1-x^2} P$ wh. we had before & this becomes same if $\bar{x} = x_1$.

$$K_2 = \frac{x_2}{1-x_2} \frac{\bar{x}}{1+\bar{x}} P$$

K_3 etc.

$$\therefore \frac{K_1}{K_2} = \frac{x_1}{1-x_1} \cdot \frac{1-x_2}{x_2}$$

$\log \frac{K_1}{K_2} = \frac{U_1-U_2}{RT}$ from ioniz^n ptl. formula.

If $K_1 = \frac{x_1^{\cancel{2}}}{1-x_1} P_1$ effective pres

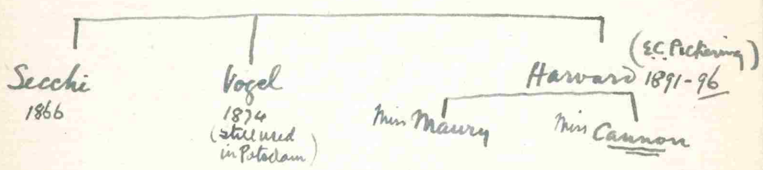
then $P_1 = P \frac{\bar{x}}{1-\bar{x}} \cdot \frac{1+x_1}{x_1}$

∴ $x_1 > \bar{x}$ gives $P_1 < P$.

i.e. in a mixture there are rather more atoms ionized for the more easily ionized ~~g~~ substance & rather less in the less easily ionized substance.

23/2/23.

Classification



Secchi. I Bluish white 4 H lines prominent. other fine lines sometimes seen. (Now known latter are always present) Sirius, Vega, Altair, Urs. maj. stars except α & Regulus, Castor

II Solar Type. Yellow. many fine lines. Mg & Fe. Sun, Procyon, Pollux, Aldebaran α Urs. maj.

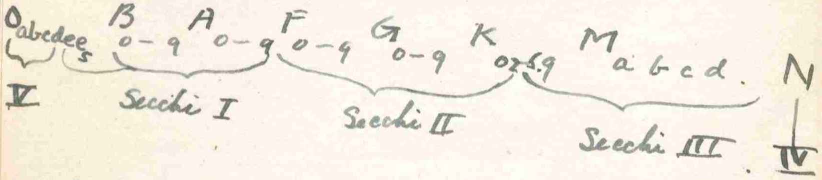
III Orange-red. "Pillars" luminous side to red shaded to violet. α Orion.

IV Rare. 6th mag. three large bands of light. luminous side toward violet. Very red

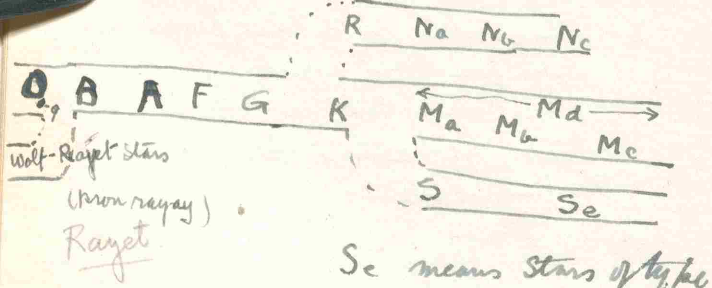
See Brit. Assoc. Report. 1868.

V (added by Pickering 1891. Bright line stars not included in above.

Harvard



Last Ap. J. suggest modification introducing S type.



Se means stars of type S showing emission lines.

This diagram has no evolutionary meaning.

Another Class P refers to gaseous nebulae

O Bright lines in general
He Spark lines. esp. λ4686.
Pickering on ζ-Puppis series (sometimes dark + sometimes bright – between H lines + due to He^+.)

Oe5 as above but no bright lines.

B Orion type (except α Orionis) – all Orion stars
He type (arc lines at max^m in B_2).
N, **Si**. O. C, Mg. Ca. H.
"Orion lines" means all the dark lines in B. stars except. H + C.
ζ-Puppis lines faintly visible in B_0.
Orion lines fade away about B_9 and H lines become more prominent.
[usually blue in colour – see Spica (α Virginis) + η Urs. Maj.]

A. Great intens. of H lines – max^m at A_0
He only found in A_0.
Mg λ4481 is prominent + max^m at A_0
Ca (H + K lines) become more prom. from A_0 – A_9
Sirius Vega (A_0) Altair (A_5)

F. Hydrogen lines as conspicuous but diminishing.
metallic lines decreasing - H,K → strong
G band begins to be conspicuous.
Pole star, Procyon, α Persei F.7.
Polaris F.8. F.7. (giant)

G. Solar Type. H + K very broad.
H lines not more conspic. than many metallic lines.
to the blue end it gets fainter.
Capella.

K_0 H K still very strong
Sunspot spectrum.
Arcturus.

K_5 Orange. α Tauri
Banded spectra begins to appear

M Bands & flutings of TiO_2 (Fowler)

N. Fluting of C + hydrocarbons

Note that very bright lines are at extremes O, B, M, Md (long period variables often) N - not found in FGK to any extent.

O stars in Milky way only -
Oes Connected with planetary nebulae
 centre + a bright shell rim out beyond -
If no emission lines Plaskett puts them in Wolf Rayet class -

---

M stars $TiO_2 \rightleftarrows Ti + O_2$.
sensitive to pressure -
Given temp upper + lower limits - of pres - are obtainable. in K_5 + M stars.
If $P = 10^{-6}$ atmos. + $T = 3500$
then 35% of mixture is undissociated
$P = 10^{-6}$ $T = 4000$ 10%
P 10^{-9} . $T = 3000$. 10%
" T 3300 very small.
P: total press due to TiO_2 Ti O_2.
If $P = \frac{1}{1000}$ total press of the atmosphere

he finds 10^{-2} atmos.
wh. is low.

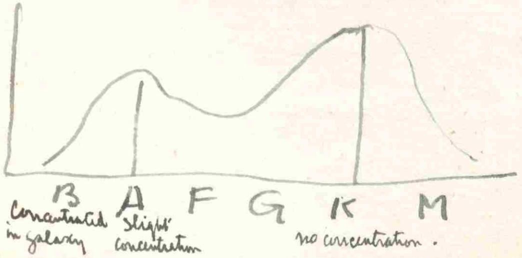
More prob value is 10^{-5} to 10^{-6}.
∴ more TiO_2 than $\frac{1}{1000}$ total press.

TiO_2 216 000 cal. Heat of formation for most other oxides only 140 000 cal.

Evidently thermodynamic condns are just right in M for formation of TiO. but gtr temp. means that it is dissociated.

See paper in MNRAS of last year.

Distribution Curve of Stars.



If a star evolves thro all types this means that time to pass thro F G < than time thro A or K.

Considerations of mass (B stars very massive) may explain few of this type.

Vel. of B stars slow.
" " K " gtr.

Formulae.

Planck. energy density of radiation

$$= u_\lambda = 8\pi hc\,\lambda^{-5}\frac{1}{e^{\frac{hc}{\lambda RT}}-1}$$

Intensity of b. b. radiation

$$= B_\lambda = \frac{c}{4\pi}u_\lambda = -hc^2\lambda^{-5}\frac{1}{e^{\frac{hc}{\lambda RT}}-1}$$

$$B = \int_0^\infty B_\lambda\,d\lambda = \frac{2\pi^4}{15}hc^2\left(\frac{R}{hc}\right)^4 T^4$$

Total emission per sq. cm from b. b. surface

$$= \iint B\cos\theta\,d\omega = 2\pi B\int_0^{\pi/2}\cos\theta\sin\theta\,d\theta.$$

$$= \sigma \quad \frac{2\pi^5}{15}hc^2\left(\frac{R}{hc}\right)^4 \qquad \text{Stefans Const.}$$

Wien's Law.

$$\frac{dB}{d\lambda} = 0 \quad \text{when} \; -\frac{5}{\lambda} + \frac{e^{hc/\lambda RT}}{e^{\text{ditto}}-1}\,\frac{hc}{\lambda^2 RT} = 0$$

Putt $x = \frac{hc}{\lambda RT}$ $\quad -\frac{5}{x} + \frac{1}{1-e^{-x}} = 0$ or $1-e^{-x} = \frac{1}{5}x$

Gives $x = 4.9651$

Follow career of a wave from small wave-length up. the increase of energy with temp.
rate of " " " increases
until a steady rate at $B_\lambda \propto RT\lambda^{-4}$

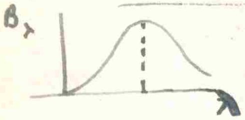
For a given T, the λ for which B_λ is increasing most quickly with T is given by $\frac{d}{d\lambda}\left(\frac{dB_\lambda}{dT}\right) = 0$

Diff. & put in x.

$$-6 - x + \frac{2x}{1-e^{-x}} = 0$$

$$\frac{x}{6} = \frac{1-e^{-x}}{1+e^{-x}}$$ giving $x = 5.9691$.

i.e. approx $\frac{5}{6}\lambda_{max}$.



Value of ordinate. B_λ at λ_{max}.

$$\frac{hc}{\lambda_{max} RT}\left(=x\right) = 4.965,$$

$$\left(B_\lambda\right)_{max} = 2hc^2\left(\frac{R}{hc}\right)^5\left(\frac{\lambda RT}{hc}\right)^{-5} T^5 \frac{1}{e^{\frac{hc}{\lambda RT}}-1}$$

$$= KT^5\frac{x^5}{e^x-1} = 21.21\,KT^5$$

where $K = 2hc^2\left(\frac{R}{hc}\right)^5$

Given an intensity curve by some means.
Try to fit a b.b. curve.

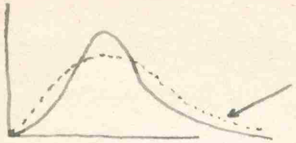
5 methods of obtaining best fit.

Assumption of b.b. radn implies that there is perfect absorption i.e. i.e. very little diffuse scattering of light by reflection from a star. Sun is not a perfect b.b. since it does not emit equally in all dirns. nor emit the b.b. frequencies. but reasonable to suppose the continuous spectrum (apart from absorption lines) approximates to b.b. case.

1. Stefans Law.
2. λ_{max} & Wiens Law. (Position of λ max)
3. Ordinate at $\lambda_m \propto KT^5 \times 21.21$.
4. Attempt to make a general fit of a b.b. curve to observed ~~fit~~ curve
5. Pairs of places. (Temps at pairs)

Abs. measure from. 1. 3
not from. 2 4 shape only.

4 gives shape 1 gives area hence abs. scale obtainable.



Planck curve of same area but not very good fit.

Compare intensities I I_0.

$$\log \frac{I}{I_0} = -5 \log \frac{\lambda_1}{\lambda_2} + \frac{hc}{RT}\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right) + \log \frac{1-e^{-\frac{hc}{\lambda_1 RT}}}{1-e^{-\frac{hc}{\lambda_2 RT}}}$$

5

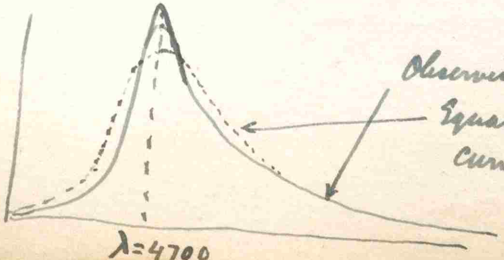
If observed curve has a very steep part.

Method 5 probably gives a Planck curve of very much too high a temp

For Sun

Values of T.

Method 1. 5740
2 6130
3 6120
4
5 } 4000 — 7000.



(Mt Wilson – corrected for atmos.)
Observed Solar curve

Equal area b. b. Stefan ~~Planck~~ curve wh. corresponds to 5740°

Extraordinary agreement in infra red but not in ultraviolet.

Ratio of maxima $\left(\frac{6.12}{5.74}\right)^5$.

Obsns from Mt. Wilson + Potsdam agree with exactitude of infra red

(See Abbot on juggling of scales to get good fit – Illogical deductions + procedure)

Pairs of places.

λλ	3000 5000	3500 50	5000 7	10000 15	4000 15
temp	3930.	5146	6900	4000	3840

fair fit.

Fits to Stars

Nordmann. Méthode hétérochrom
takes limited regions of star + applies Planck formulae.

Sun – 5320°
Polaris 8200°
α Lyrae 12200°
λ Tauri 40000° – too high but

Certainly indicate changes ~~order~~ of temp in diff. classes —

Wilsing + Scheiner Potsdam

Potsdam Publications Vol. 19. 1900
Bd. 24. 1919.

Most extensive temp measurements.

$I_1 = k\lambda^{-5}(e^{-} - 1)^{-1}$ Intensity by photometer.

$\log I_1 = \log K$ —— ——

$\log k = x$ $= y$

—— —— — — —

$a = x + by$?

by least sqs find best values –

Andromeda	A_0p	9400.
Polaris	F8	5600
α Tauri –	K_5	3500
Arcturus	K_0	3700
Regulus	B_8	10,000

They took mean values for diff spectral types.

B_0	10700
B_5	10500
A_0	9700
F_0	7,300
G_0	5200
K_0	4400
K_5	3500
M	3100

They seem believable up to A_0 but the B_0 B_5. temps seem incredibly ~~large?~~ low?

Consider where max^m wd. by.
at 6000° max. 4700 for Sun
" 12000 by Wiens law. $\frac{4700}{2\frac{1}{2}\text{ approx}} = 1900$
wh. is away in ultra violet –

Russells suggestions. See subpage 7.

B_0	20,000
B_5	14 000
A_0	11 000
F_0	7500

Need now felt for separating out giant & dwarf temps. this accounts *perhaps* for previous low values of B_0 B_5 –
Latest Method not a visual one as above or ~~photometer~~ but photometric by thermopile or photoelectric — Sampson.

Refs. to Thermopile Work

See W.W. Coblentz. B. of Standards 11. p.613. 1914-15
Vacuum thermopile at Lick & in Arizona
Also Lick Obs. Bul. 8. 266 p.104. 1915.
Ap. J. 55. 21. 1922.
Proc. Nat Acad of Sci. 8. 49. 1922.

Copied from C.P.   at p. 65   1

Measurement of Heat from Stars

1. Thermoelements   2. Radiometer   3. Selenium.

1. Huggins 1868.9   Bi. Sb.

8" refractor

Stone. $\frac{\text{Arcturus}}{\text{Vega}} = \frac{3}{2}$ right order.

Pfund. Vacuum thermocouple. Eliminates convection.

Alleghany Obs. Transactions $\frac{\text{Vega}}{\text{altair}} = 3.7$

2. Nichols. 1901. Deflections up to 1 mm. $\frac{\text{Arc}}{\text{Vega}} = 2.2$

Sensitivity. 724 mm. for 1 candle at 1 metre

This corr. to 1 mm . . . . 5 miles.

3. Selenium Cell - now abandoned

Coblentz. Single junction receivers very small.

Vacuum with fluorite window. First expt on

Crossley reflector (Lick.)

Large deflections for red stars - small for blue.

Says his sensitivity. 500 x that of any other observe

200 results from receiver -

{Arcturus - 10^{-8} candle at 1 metre,

{1 mm deflection given by a candle at 53 miles

using telescope as a collector.

α Urs. Maj. ~~[illegible]~~ Yellow $1^m.95$

ε . . Blue 1.68 $\frac{\alpha}{\varepsilon} = \frac{2}{1}$

Brightest N star 19 Pisc 5.3
M ϕ Peg $\frac{19}{\phi} = 2$.

Certain red stars give small deflections - due to being binaries - (method for detecting binaries ?)

1 cm H_2O interposed. Cuts out region beyond 1.4 μ.

α Lyrae	A	58 %
α Aurigae	G	48 %
α Bootis	K_0	45 %
α Tauri	K_5	35 %
α Orionis	Ma	27 %
α Herculis	Mb	21 %

~~Later~~ Later Water transmission.

ϵ Orionis	B_0	1.75	.66 cm	81 %
β "	B_8	0.34	2.9 cm	63 % (binary)
α Lyrae	A_0	0.14	3.6 cm	75 %
Sirius	A_0		10.6 cm	65 %

See Pub. Pac. Ast. Soc.

Assume blackness + apply to red + blue star for rel. total intensities.

Same apparent visual mag. means same intensity at earth in some partic. λ.

Let A_1 A_2 be areas of app^t^ discs
R_1 R_2 distances from earth
B_1 B_2 surface brightnesses visable in λ
T_1 T_2 temps.
I_1 I_2 app^t^ brightnesses.

Then $I_1 = \frac{A_1 B_1}{R_1^2}$ $I_2 = \frac{A_2 B_2}{R_2^2}$

$B_1 = \frac{c_1 \lambda^{-5}}{e^{-\frac{c_2}{\lambda T_1}} - 1}$ $B_2 = \frac{c_1 \lambda^{-5}}{e^{-c_2/\lambda T_2} - 1}$

Put $I_1 = I_2$

$$\frac{c_1 \lambda^{-5}}{e^{\frac{c_2}{\lambda T_1}} - 1} = \frac{A_2}{A_1} \frac{R_1^2}{R_2^2} \frac{c_1 \lambda^{-5}}{e^{\frac{c_2}{\lambda T_2}} - 1}$$

Using Wien's form

$$e^{-\frac{c_2}{\lambda T_2}} = \frac{A_2}{A_1} \frac{R_1^2}{R_2^2} e^{-c_2/\lambda T_2}$$

Let E_1, E_2 be total radiations.

$E_1 = \frac{\sigma T_1^4 A_1}{R_1^2}$ $\frac{E_1}{E_2} = \left(\frac{T_1}{T_2}\right)^4 \frac{A_1}{A_2} \frac{R_2^2}{R_1^2}$

$\therefore \left(\frac{T_1}{T_2}\right)^4 e^{\frac{c_2}{\lambda}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)} = \frac{E_1}{E_2}$ Areas + distances go out.

If $T_1 = 3000$
$T_2 = 10000$ then $\frac{E_1}{E_2} = (0.3)^4 e^{6.27}$
$\lambda = 5200$
$\simeq 4.3$

same order as Coblentz.

$$\frac{T_1^4 e^{\frac{c_2}{\lambda T_1}}}{T_2^4 e^{c_2/\lambda T_2}}$$

"Emissivity M" $=$ Total emission / Luminous emission

$=$ energy / light

Then we have found M_1/M_2.

$$M = \frac{T^4\left(e^{\frac{c_2}{\lambda T}} - 1\right)}{\lambda^{-5}}$$ Put $\frac{c_2}{\lambda T} = x$

$$= T^4(e^x - 1) \Big/ \lambda^{5-}$$

$$\frac{dM}{dx} = -\frac{4}{x} + \frac{1}{1-e^{-x}} = 0$$

$$x = 3.92$$

$$T = \frac{c_2}{3.92\lambda} = 7\,000$$ near temp of Sun
Type F.

e.g. Take $T_2 = 7000$ $\frac{E_1}{E_2} = 6.3$

$$\frac{M}{M'} = \frac{T^4\left(e^{\frac{c}{\lambda T}} - 1\right)}{T'^4\left(e^{\frac{c_2}{\lambda T'}} - 1\right)}$$

T	$\frac{M}{M'}$
2000	117
3000	6.6
4000	2.2
5	1.4
6	1.~~92~~15
7	·92
8	1.16
10 000	1.39
12	1.76
20	4.57

Take β Draconis (G)
$3^m.0$ 6000
Coblentz 6.44
Intensity ·064
Arcturus (K) $0^m.24$
8.58.
Intens - ·820

$$\text{Ratio } \frac{\frac{8.58}{0.82}}{\frac{6.44}{\cdot 64}} = 1.52$$

Value for 6000 = 1.15

1.52 × 1.15 = 1.74

∴ By interpolation Arcturus has temp 4500.

Angular Diams. + Surface Brightness.

Appt. Mag. is a no. $\propto$ $-\log$(appt. intensity of starlight in λ)

Const of proportionality is equivalent to light-ratio of 100

m = mag

I = obs. brightness

$$m_1 - m_2 = -a\left[\log_{10} I_1 - \log_{10} I_2\right]$$

when $m_1 - m_2 = 5$ $\quad \frac{I_1}{I_2} = 100$

$$\therefore m = -\frac{5}{2}\log_{10} I + \text{const.}$$

or $\log_{10} I = -0.4\, m + \text{const.}$

$\sqrt[5]{100} = 2.512$ Thus light ratio is $2\frac{1}{2}$ approx.

Abs. Mag. is app. mag. at dist given by 10 parsecs.

π = parallax of star

M abs. mag. where $\pi = 0''.1$

1 parsec $\doteqdot 3\frac{1}{3}$ light years.

I = appt. intensity

π = parallax

$$I_{\pi=0.1} = I \times \left(\frac{0.1}{\pi}\right)^2$$

$$m = -\frac{5}{2}\log_{10} I + \text{const}$$

$$M = -\frac{5}{2}\log_{10}\left(\frac{.01}{\pi}\right)^2 + \text{const}$$

$$M - m = \frac{5}{2}\log \pi^2 - \frac{5}{2}\log .01$$

$$= 5\log \pi + 5$$

$\therefore M = m + 5 + 5 \log_{10} \pi$

eg. π for Sun = 1 radian

appt. mag. = -26.72

$M = 4.85$.

?

Is this Eddington's work or Saha's –

d = Ang. diam in sec.

m = appt mag.

r = dist.

T = temp

λ = wave length corres. to m.

$$\text{Intensity} = 10^{-0.4m} \propto \cancel{r} d^2 \frac{\lambda^{-5}}{e^{\frac{hc}{RT}} - 1} \frac{1}{r^2}$$

$$\log_{10} d = -0.2m + \frac{.4343}{2} \frac{hc}{\lambda R T} + \text{const}$$

where we have used the Wien approximation

Const. detd. from Sun

$d = 1920''$ $\quad \lambda = 5200$

$m = -26.72$

$T = 6000$ $\quad \frac{hc}{R} = 1.4325$

$\therefore$ Const $= -3.05$

Ang. diams from temps.

			diam	obs.
α Orionis	3000	$1^m.92$	0".059	0".46
	3100		0".50	
α Bootis	4500	0.24	0".017	0".022
	4300		0".020	

H N Russell d = ang diam
D = true "
J = surface brightness.
R = distance

Intensity $= J \times \frac{\frac{1}{4}\pi D^2}{R^2} = \frac{1}{4}\pi d^2 J$

$= 10^{-0.4 m}$

Thus $d = \text{const} \times J^{-\frac{1}{2}} 10^{-0.2 m}$

Surface brightness J for Sun $= 1$

Const $= .0087$

$d = 0087\ J^{\frac{1}{2}}\ 10^{-0.2 m}$

Let $j = -2.5 \log_{10} J$ exp in mags.
j for Sun $= 0$.

$d = 0.0087\ 10^{-0.2 m + 0.2 j}$

$= 0.0087 (10^{-0.2})^{(m-j)}$

∴ Stars of small j will have small d.

Calculation of j from Colour index

Colour index $m_\phi - m_v$

Blue stars have neg. c.i. } varies from small neg values to about +2.
Red " " pos. c.i.

For A type c.i. $\doteqdot 0$ This defines the scale
K c.i. $\doteqdot 1$

J & J' be surface brightnesses in λ & λ'
I I' appt. intensities

$$\frac{J}{J'} = \frac{I}{I'} = \left(\frac{\lambda}{\lambda'}\right)^{-5} e^{-\frac{hc}{RT}\left(\frac{1}{\lambda}-\frac{1}{\lambda'}\right)}$$

$$i = m' - m = +2.5 \log_{10} \frac{I}{I'}$$

$$= -2.5\left[5 \log \frac{\lambda}{\lambda'} + \frac{hc}{R} \frac{.434}{T}\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right)\right]$$

For two stars use suffixes 1 & 2.

$$i_1 - i_2 = 2.5 \frac{hc}{R} \times 434 \left(\frac{1}{\lambda'} - \frac{1}{\lambda}\right)\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

If $T_1 < T_2$ $\qquad i_1 > i_2$

But $j_1 = -2.5 \log_{10} J_1$

$$\therefore j_1 - j_2 = -2.5 \log_{10} \frac{J_1}{J_2}$$

j's refer to visible wave lengths

$$= 2.5 \times 4.34 \frac{hc}{\lambda R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\therefore \frac{i_1 - i_2}{j_1 - j_2} = \frac{\lambda - \lambda'}{\lambda'}$$ positive.

A stars defined to have $i = 0$

Then $i = 2.5 \times 434 \frac{hc}{R}\left(\frac{1}{\lambda_1} - \frac{1}{\lambda'}\right)\left(\frac{1}{T} - \frac{1}{T_A}\right)$

Diff. observers may be using diff λ's + λ''s

Mul. c.i. by a factor to make $i = 1$ for K stars

$$i = \frac{\frac{1}{T} - \frac{1}{T_A}}{\frac{1}{T_K} - \frac{1}{T_A}} \qquad \begin{aligned} T_A &= 10\,800 \\ T_K &= 4\,400 \end{aligned}$$

$$\frac{T}{10800} = \frac{0.69}{i+0.69}$$

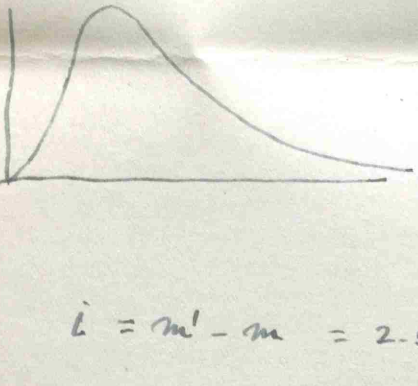
$$\frac{T_1}{T_2} \text{ for any star } = \frac{i_2+0.69}{i_1+0.69}$$

·053 for Sun
$T = 6100$

See Pub. Pac. Soc. 1919.

Wien's law begins to break down for hot stars

at high T° the c.i. tends to a limit
It is ∴ an insensitive $f(T)$



for large T
photovisual λ

$$I \propto T\lambda^{-4}$$

$$\frac{I}{I'} = \left(\frac{\lambda}{\lambda'}\right)^{-4}$$

$$i = m' - m = 2.5 \log \frac{I}{I'}$$

$$= 10 \log \lambda/\lambda'$$

Wh. is indept. of T

True value of i

$$i = 2.5\left[-5 \log \frac{\lambda}{\lambda'} + \frac{hc}{R}\frac{.434}{T}\left(\frac{1}{\lambda}-\frac{1}{\lambda'}\right) + \left(\log \frac{1-e^{-hc/\lambda' RT}}{1-e^{-hc/\lambda RT}}\right)\right] = \begin{matrix} 0.035 \text{ for } T=10,000 \\ 0.4 \text{ " } T=20000 \end{matrix}$$

Hirschmann Leyden Annals

Detection of Colour equivalents – (all kinds

Tabulates $\frac{hc}{RT}$ It does not shift at all from $B_0 - B_8$

B_0	1.48
B_5	1.36
B_9	1.50
A_0	1.48

Colour Indices

H. D. cat.

B_0	−0.24	F_5	0.42
B_5	−0.12	G_0	0.56
A_0	0.00	G_5	0.78
A_5	0.14	K	1.00
F_0	0.28	K_5	1.18
		M	1.35

HN Russell formula.

$\lambda = 5200$ $\lambda' = 4200$

$\frac{\lambda'}{\lambda - \lambda'} = 4.2$ HNR takes 4.

$j = 4(i - i_0)$

A_0	A_5	F_0	F_5	G_0	K_0	Ma	N
−2.1	−1.3	−1.0	−0.6	±0.0	1.9	3.7	6.3

And using $d = .0087\ 10^{-2(m-j)}$ calculates Ang. Diams

α Orionis	0".031
Antares	.028
α Tauri	.024
Arcturus	.019
Sirius	.007
Vega	.002

Nicholson + Pettit - Radiometric mag.
(using total rad^{n})

Heat index = vis. mag. - radio mag.
Large for stars of low temp

	vis.	radio.	h.i.	Transmission/Total in H_2O
α Lyrae	0.14	0.14	000	.32
α Bootis	.24	-0.99	1.23	0.76
α Orionis	.97	-1.49	2.4	1.19
R Leonis Md LPV	9.2	1.10	8.1	2.19
o Ceti near Min^{m}			7.7	

Reduced to 0 for A.

o Ceti Observed when Hooker at Mt. W. Obs. mag. 8.9 (not far from min^{m})

total/visual much larger than for type Ma.

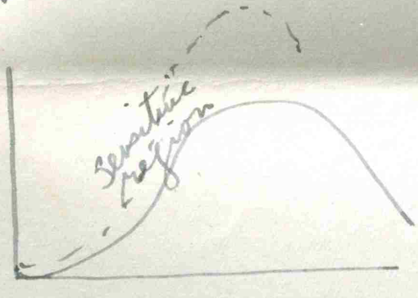
α Ceti:

				T_0
m = 2.8	Ma gave	25.9	(min)	3300
o Ceti				
m = 8.9	Ma	"	13.8 (")	1700

$$\frac{dI_\lambda}{I_\lambda} = 5\,\frac{\lambda_{max}}{\lambda}\,\frac{dT}{T}$$ where Weins Law holds.

for small λ compd to λ max a huge change in I accompanies a given change in T

$$I_\lambda \propto T^9$$



If o Ceti has T = 3000 at max it wd. give increase of $7^m.5$

actual range = 1.7 — 8.9.

5/3/22. Saha's paper in Proc. R. S. ←

1. Low temp lines
2. Lines with a max^m at some stage
3. Lines appearing at high temp - still increasing

1 usually unenhanced & often of a princ series
ex. λ 4227 Ca I line

2. Balmer lines.
Lines H + K of Ca
Mg 4481 arc lines
N^+ C^+
λ 4435
4455 ? Ca triplet
4025
λ 5180 Mg.

3. He^+ 4686 & ξ Puppis.

Saha theory accounts for those . . . .
word protoelement for enhanced spark lines.

The max^m come in order of ioniz^n ptl.

Saha Table shows Ca completely ionized at 13000 (i.e. 1.5% unionized left) & line λ4227 just vanishing . . . B.8.

Also . . . . 2^nd . . . . 20000 H, K . . O_e

C^+ app. 4000 Mb

13.54 Balmer line at 2000

15.00 Mg. 23000

∴ Mg lines should

persist longer than Balmer lines — but they do not. This is the great trouble not completely explained by Saha.

2p orbit: (2 quantum) H should appear at 4500 — ∴ M.

2p " He shd. appear at 12000 ∴ A_0

Saha does not make plain whether these be interpolated pts on his scale or calculated pts.

Summary of Scale.

	B_0	B_5	A_0	F_0	G_0	K	K_5
Saha	18000	14000	12000	9000	7000		
Russel	20000	14000					
1914	10700 12–14000	10300	11000 9700 11000	7500 7300	5000 5200	4200 4400	3200 3500
	Ma		Mb				
	5000		4000				
	3100 3150						

W & S

Coblenz

Saha is certainly too high from G_0 on due to taking a wrong Solar const as datum line.

Russells lecture 1914 on giants & dwarfs — temps based on Colour indices see Eddingtons Stellar movements.

$\frac{0.7}{-0.7} = \frac{T}{10800}$

got from $i = \dfrac{\frac{1}{T} - \frac{1}{T_A}}{\frac{1}{T_K} - \frac{1}{T_A}}$

$T_A = 10800$ $\quad T_K = 4400$

Colour index not a sensitive function but Russels deduced temps seem very reliable.

Saha temp shd. be accurate temp of the reversing layer & equal to effective temp of star.

Saha scale more exact if pressures better known.

Work of Milne & Fowler.

1. Increasing ioniz^{n} diminishes no. of atoms capable of absorbing - fraction y
2. Increasing no. of atoms in 2 quantum state f

Then no. of atoms cap. of absorbing Balmer $\propto fy$

Very low temp f very small
" high " y " "

∴ a max^{m} between.

Quantitative measurement depends on Stellar series - Take the max^{m} - & get Temp.

Saha method was to find marginal appearance or disappearance & can never be ultimately satisfactory bec. no of atoms not known - i.e. x

Let x = degree of ionization

$$\frac{x}{1-x} P_e = C\,T^{5/2} e^{-\frac{\chi_1}{kT}}$$

λ_1 = ionis ptl.
k = Boltzmans const
C = Chem Const.

Fraction of non-ionized atoms wh. are in quantum state 2 is by Statistical mechanics

$$e^{-\frac{\chi_1 - \chi_2}{kT}}$$

χ_2 = energy level corresp to state 2.

∴ $\chi_1 - \chi_2$ = energy req^{d} to lift electron from state 1 to state 2.

Solving above eq^{n}

$$x = \frac{C}{P_e} \frac{T^{5/2} e^{-\chi_1/kT}}{1 + \frac{C}{P_e} T^{5/2} e^{-\chi_1/kT}}$$

∴ no of atoms in State 2

$$\propto (1-x)\,e^{-\frac{\chi_1 - \chi_2}{kT}} = n$$

$$= e^{-\chi_1 - \chi_2/kT} \Big/ 1 + \frac{C}{P_e} T^{5/2} e^{-\chi_1/kT}$$

$$= \frac{e^{+\chi_2/kT}}{\frac{c}{P_e} T^{\frac{5}{2}} + e^{+\chi_1/kT}}$$

Diff. this w.r. to t for maxᵐ.
unique value

$$\frac{dn}{dt} = 0 \qquad e^{\frac{\chi_1}{kT}} = \frac{\frac{c}{P_e} T^{5/2} \frac{\chi_2 + \frac{5}{2}kT}{}}{\chi_1 - \chi_2}$$

$$P_e = c T^{5/2} e^{-\frac{\chi_1}{kT}} \frac{\chi_2 + \frac{5}{2}kT}{\chi_1 - \chi_2}$$

Here at maxᵐ $1 - x = \frac{\chi_2 + \frac{5}{2}kT}{\chi_1 + \frac{5}{2}kT}$

---

for H $c = \frac{.332}{2}$ $\chi_1 = 13.54$ volts.
χ_2 = resonance - ionizⁿ pot
= 3.385 volts

~~[illegible]~~ T = 10,000

kT = 0.86 volts

Then get $P_e = \underset{1.3}{\overset{1.3}{\cancel{7.2}}} \times 10^2$ dynes/cm²
= 7.2 10⁻⁴ atmospheres.

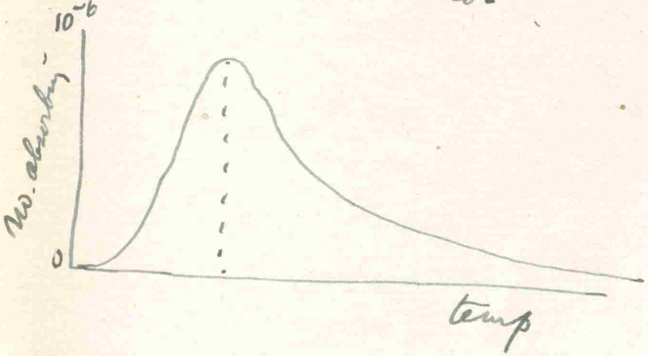
If in A0 Balmer attains maxᵐ
this gives partial pressure.

If T 11000
$P_e = 7.3 \, 10^2$

For Mg. c = ·332 χ_1 = 15·00
χ_2 = 6.15

If T = 10000
$P_e = 0.82 \; 10^2$
$= .82 \; 10^{-4}$ atmos

If T = 11000
$P_e = 5.2 \; 10^{-4}$ atmos



T 14000 Helium
$\chi_1 = 25.4$ χ_2 3.61
$P_e = 1.74 \; 10^{-6}$ atmos.

T 17000 $P_e = 1.2 \; 10^{-4}$ "

Fair agreement.

P_e : partial pres. of electrons.

This is 1000 times lower than pressures assumed by Russel + Saha.

Ca.	Sharp singlets.	T 5000	P_e 5.9·10^{-4}
Na	" doublets	4000	2.2 10^{-4}
Mg	" diffuse singlets.	6000	3.9 10^{-4}

temps are selected at maxm intensity. & all gives same order of pressure.

2nd stage ionization in Ca H&K lines gives same order though lower maxm than 6000

6000 3.6 10^{-5}
5000 7 10^{-7}

7/3/22. Let χ_1 = first stage I.P.
χ'_1 = 2nd " "

Let fraction of once ionized atoms = x
" " twice " " = y
Electron pressure = P_e.

1st stage
$$\log \frac{x}{1-x-y} P_e = -\frac{\chi_1}{kT} + \frac{5}{2}\log T + \log \frac{(2\pi m)^{3/2} k^{5/2}}{h^3} - \log B(T)$$

last term see Fowlers paper (for rotational energy)

2nd stage
$$\log \frac{y}{x} P_e = -\frac{\chi_1'}{kT} + \frac{5}{2}\log T + \text{"} - \log B'(T)$$

Note χ_1' is additional energy above χ to remove 2nd electron.

From these
$$x = \frac{1}{1 + \frac{P_e}{c} T^{-\frac{5}{2}} e^{+\frac{\chi_1}{kT}} + \frac{c'}{P_e} T^{+\frac{3}{2}} e^{-\frac{\chi_1'}{kT}}}$$

Where $c = \frac{(2\pi m)^{3/2}}{h^3} k^{5/2} \frac{1}{BT}$.

If $\frac{dx}{dT} = 0$
$$\therefore \frac{P_e}{c} e^{\frac{\chi_1}{kT}} \cdot \left[\frac{5}{2} T^{-\frac{7}{2}} + \frac{\chi_1}{kT} T^{-\frac{7}{2}}\right]$$
$$= \frac{c'}{P_e} e^{-\frac{\chi_1'}{kT}} \left[\frac{5}{2} T^{\frac{3}{2}} + \frac{\chi'}{kT} T^{\frac{3}{2}}\right]$$

i.e.
$$\frac{P_e^2}{cc'} = \frac{\chi_1' + \frac{5}{2} kT}{\chi_1 + \frac{5}{2} kT} T^5 e^{-\frac{\chi_1' + \chi_1}{kT}}$$

or
$$P_e = \sqrt{cc' \frac{\chi_1' + \frac{5}{2} kT}{\chi_1 + \frac{5}{2} kT}} \cdot T^{\frac{5}{2}} e^{-\frac{1}{2}\frac{\chi_1 + \chi_1}{kT}}$$

In calculations $c = c'$ $B(T) = 1$ generally

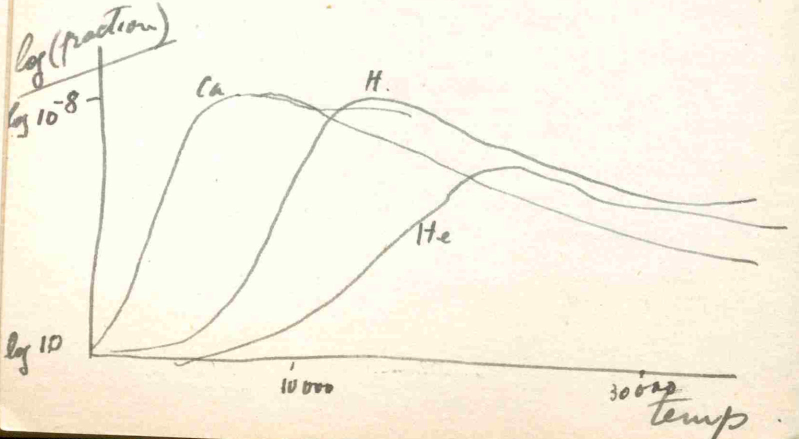
Thus for Ca 1S. term = 49.305
1σ+ , = 95740

In ioniz^n ptls. $\chi_1 = 6.10$ volts.
$\chi_1' = 11.82$.

If $T = 6000$ $kT = 0.52$ volts.
$T^{\frac{5}{2}} = 2.79\,10^9$
$\frac{1}{2}\overline{\chi_1 + \chi_1'} = 8.96$

$P_e = 3.55 \times 10$ dynes cm^{-2}
$= 3.55\ 10^{-5}$ atmos.

Note that 2nd stage ioniz usually only begins as 1st stage is almost complete but for subordinate series.



Zinc lines. 4680
4722 (1p-1S)
4810.

Is weakened at lower temps.

Adams + Joy compared these for Sirius. Procyon + Arcturus with Fe lines.

In S. greatest intens
P prominent.
Arc. Fainter than in Sun.

This progression pts. to a max^m. at temp > Sirius.

Try 9000

$\chi_1 = 9.35$ 1st ioniz^n.
$\chi_1' = \cdot 35$ Resonance ptl

$P_e = 2.6\ 10^4$ dynes cm^{-2}.
$= 2.6\ 10^{-2}$ atmos

for 8000 Pe comes $4.2\ 10^{-3}$
7000 $4.2\ 10^{-4}$
wh. is certainly too low a temp.

Heights of lines of this triplet are given low in Lebel tables. 400 km. hence probably high pres. is genuine.

Spectroscopic Parallaxes.

Refs. Kohlschütter Ap. J. 1914

Adams - Diffs in Spectra between stars of large & small Proper motion. (before giant + dwarf theory)

Adams. Proc. Nat. Acad. Sci. ✓
2. 143. 1916.

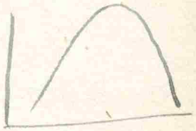
Adams + Joy. Ap. J. 46. p. 335. 1917
List of 500 stars.

Adams. Ap. J. Jan 1921 p. 13.
List of 1646 stars ✓

Lockyer noticed diffs of detail of same spectral types, enhanced lines etc.

Russell
i.e. 2 classes.

Giants + dwarfs.



Assume stars of same spectral type have same effective temp but low pres. bring enhanced lines + high ∴ weaken lines.

Consider cause of effective pressure

"g" In region of continuous spectrum order of mag. of optical depth is same for two stars of same temp.

Let x inwards = depth

$$\frac{dp}{dx} = g\rho$$

$$\frac{d\tau}{dx} = k\rho \qquad k = \text{abs. coeff}$$

$$\frac{dp}{d\tau} = \frac{g}{k}$$

$$p = \frac{g\tau}{k} \qquad \frac{p}{g} = \frac{p'}{g'}$$

i.e. small p goes with small g.

$g = \frac{M}{r^2}$ small for small M or large r.

Masses do not vary much.

∴ small g arises from large r.

i.e. small pres. in reversing layer means gt. r + enhanced lines in spectrum.

Luminosity increases with M.

More luminous are more massive.
more massive have smallest g generally
$\therefore$ More luminous have smallest g.
Adams plots these values.

(a) λ 4216 Sr^+ λ 4250 Fe Mn
(b) λ 4455 Ca 4462 Fe
(c) λ 4455 Ca 4495
Sensitive lines. not very sensitive

Intensity of Sr^+ line increased with luminosity.
" " Ca " decreased " "

Empiracal equations
(a) $F_5 : F_6$ $M = -1.9\,\Delta + 5.2$
M = abs. mag.
Δ = diff. in intensity.
Constants varied with type.

(b) $M = 2.0\,\Delta + 3.3$
(c) $M = 2.8\,\Delta + 2.6$.

Use backwards to get π.
from. $M = m + 5 + 5 \log \pi$.

Scale built up on trig. parallaxes —

Accuracy is fair only — ! ? ! —
see ASE & AvW paper.

for distant stars it is not increased.
$M = m + 5 + 5 \log \pi$
$\delta M = 5 \frac{\delta \pi}{\pi} \log_{10} e$
Error in $\pi \propto \pi$.

See Strömberg on systematic errors.

Rel. intensities of Balmer Lines
Mt. Wilson method of classification of stars gave some diffs. from Harvard classfn.
~~i.e. High [illegible] luminosity~~
α Orionis G2 instead of K_5.
Some high luminos M " " G8.

In general.

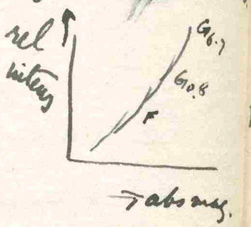
		Average.	No.	Average abs mag.	
High luminos		$G^{4}7$	48	+1.4	-1.0 to 3.4
Low		Ma	10	+10.3	+9.8 to 10.7

In former low pressure comes in + no. in 2nd ionz^n state is altered.

Fowler thinks in low lumin most of H is molecular

RAS. paper March. Abs. mag by Spec Intens

Pairs of lines 4215 Sr.+ 4250 Fe



curves almost the same

∴ error in selecting sp. type does not alter abs. mag.

Milne says wd it hold true for all pairs e.g. 4215 Sr+
4227 Ca.

since one increases with temp + one falls –

Russells Giant & Dwarf Theory.

Nature 1914 – p 227 vol. 93

Consider M stars.

Total brightness = Surface brightness × area.

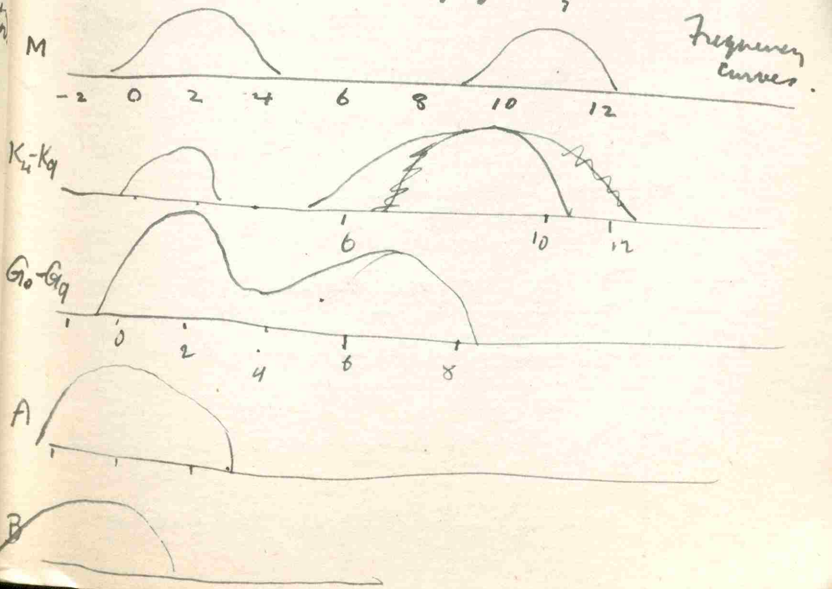
∴ Abs. bright must have large r

∴ dim of same type ∴ ∴ small r.

or large mass + low density – + v. v.

Given spectral type $r^3 \propto \frac{M}{\rho}$.

In practice M varies very little + density very greatly.

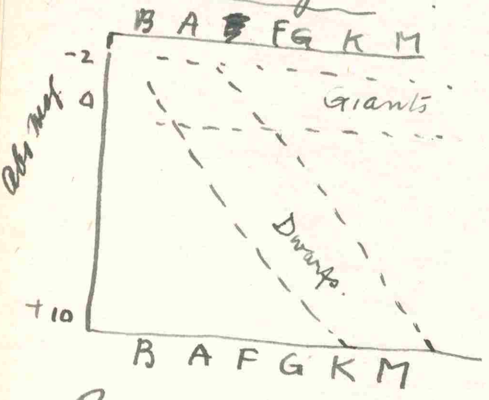


Note gap of M + K_u K_g.

Note that Abs. mag. — 5 corresponds to 7500 X Su
0 " " 100 X ⊙
+5 " " Sun
+14 " " $\frac{⊙}{5000}$

This gigantic gap is one of the most extraordinary things in physics.

Russell's Diagram



Represent every star by a dot & there cluster in 2 bands.

Russells 3 deductions

1. All white stars are very bright
i.e. > ⊙
All very faint stars are orange or red.
(the converse not true)
For any spectral type there is a

limiting magnitude fainter than which there are no stars.

2. But there are many red stars of gt. abs. brightness.

3. All M & K stars are either very bright or very faint.

Hence from F to M divide into 2 classes Giants + Dwarfs.

Giant means high luminosity.
Dwarf " low "

but given spectral type it also means large + small in linear dimensions.

Convenient to extend Giant name along band + say all B stars are giants -

for giants surface brightness × area = const
∴ linear scale gets smaller along the giant band.

Repetition of this diagram with fuller data
see Sears Ap. J. last year.

Only evidence of mass is from spectroscopic binaries – gravitational attrn.
Small range. ½ ☉ to 3 or 4 times ☉
but exceptional stars 60 × ☉.
10 to 100 fold range of mass.

Luminosity range – about 10^7
-3 to $+14$
17 mags $(100)^3 = 10^6$

Correlation between mass + type

B	A	F	G	K	M	
~~3~~	~~2~~	1.7	0.5	0.3	0.2	Dwarf mass
3	2	–	3.0	1.5	1.5	Giant

Average mass

B_0	B_5	A_0	A_5	F_0	F_5	G_0	G_5	K_0	K_5
10	8.3	6.0	4.0	2.5	1.5	1.0	0.8	0.7	0.6

dwarfs mostly

Largely from binaries.
Spec binaries chiefly B_0 – F
Visual " " F – M

Abs. mag. of Sun is +5 Dwarf.

Hence assume giant M stars
must have small densities

Av. gap of 10 mag
$(100)^2 = 10^4$.
$10^4 : 1$ is ratio in luminosity
giant M : dwarf M.
Surface $10^4 : 1$
∴ radius $10^2 : 1$
∴ density $10^6 : 1$

At limit a dwarf M cannot have
density more than 10

Earth 5.5
Sun 1.4.

∴ giant limit is 10^{-5}.
i.e. $\frac{1}{100}$ that of ordinary air.

Now estimate dens. of A star.
Surface area × brightness = const
for giants.
3000° to 11000°
brightness goes up as $\left(\frac{11}{3}\right)^4 = 180$

∴ surface $\frac{1}{180}$

∴ $(180)^{3/2} = 2{,}500$ = density of A above M.

∴ 10^{-2} to 10^{-1} for A stars

Evidence for these low densities

Eclipsing binaries

plane of orbit in plane of sight

Pos. to find ratio of axes. from light curve

P = period

a = maj. axis of orbit

M = mass

$$P^2 \propto \frac{a^3}{M}$$

$$P^2 \propto \left(\frac{a}{r}\right)^3 \frac{r^3}{M}$$ r = radius of star

$$\propto \left(\frac{a}{r}\right)^3 \frac{1}{\rho}$$

$$\therefore \rho \propto \left(\frac{a}{r}\right)^3 \frac{1}{P^2}$$

P known from eclipse & from light

curve find ~~r + a~~. $\frac{a}{r}$.

At Princeton Shapley & Russel have analysed light curves – many difficulties –

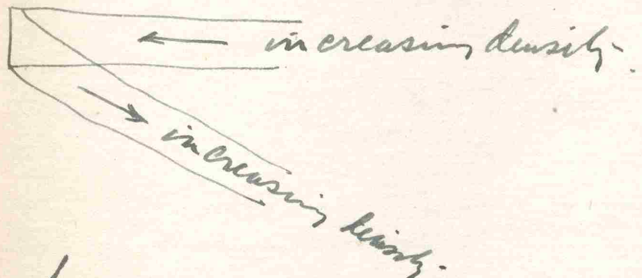
B, A $\frac{1}{3}$ to $\frac{1}{45}$ density of Sun.

G, K vary enormously

$2 \times \odot$ to $\frac{1}{100{,}000} \times \odot$.

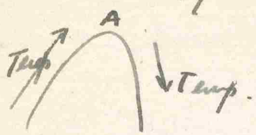
Very low densities only found in G & K.

All evidence completely confirms Russells theoretical work on densities



hence idea of life history of a star contraction along Giant path & then further along Dwarf path.

Previously idea suggested by Sir N. Lockyer.



yet idea not well diffused

& Russells thy. came as a shock to Sci. world.

Lane on Temp of a gas.

adiabatic equilibrium.

$$\frac{dp}{dr} = -g\rho \qquad \frac{p}{\rho} \propto T$$

$$\frac{p}{\rho^\gamma} = \text{const.} \qquad (\gamma-1)\frac{d\rho}{\rho} = \frac{dT}{T}$$

$$\therefore \frac{dT}{dr} \propto -g$$

$$\propto -\frac{M(r)}{r^2}$$

transform putting $r = x r_0$

Where r_0 = radius of star.

x goes from 0 to unity.

$$r_0 \frac{dT}{dx} = -\frac{M(x)}{x^2}$$

$M(x)$ = mass included within sphere of x radius.

$r_0 T$ is a fn. of x only.

$r_0 T$ is constant during evolution at any pt fixed relatively to structure of star.

$\therefore r_0 T_c$ = const.

T_c : temp at centre

$$T_c \propto \frac{1}{r}$$

$\therefore$ increases as r decreases.

We deal with effective temp wh. prob. $\propto T_c$

$\therefore$ Russell says when star turns the corner G. to D. it then ceases to be a perfect gas

Also higher the mass, higher the temp before turning ? ✓

Giant stage rapidly passed thro
Dwarf " slowly " along.
∴ more of latter.

Caanmers Theory -

Five lines in Stark effect are sharpest in violet & diffuse in red

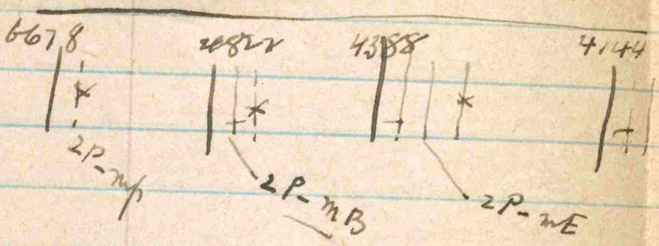
Ionized He likewise 4686 1st l. Fowler Ser

$$\frac{\Delta\nu \text{ for } H_\beta}{\Delta\nu \text{ for } 4686} = \frac{24}{4^2-3^2} \quad \text{Bohrs theory}$$

$$= \frac{24}{3^2-2^2} \quad \text{by experiment.}$$

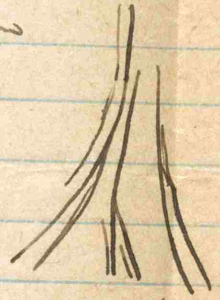
1 line gives 1, 2, or 3 Stark lines

H_γ & 4388 He



new appearing lines shows others originally displaced towards violet, slightly towards red.

True doublet 4026 orthohelium



incline slit toward + ions & look for Doppler effect
negligible effect for +He ∴ not many of them
+H ions may carry the cur. bec. there was always a haze.

Caanmers Theory -

Five lines in Stark effect are sharpest in Violet & diffuse in red

Ionized He likewise 4686 1st of Fowler Series

$$\frac{\Delta\nu \text{ for } H_\beta}{\Delta\nu \text{ for } 4686} = \frac{24}{4^2-3^2} \quad \text{Bohrs Theory}$$

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H_γ & 4388 He

· PHYSICS ·
OF THE
· EARTH'S · INTERIOR ·

A. Douglas.

A. V. Douglas.

Cavendish Lab.
Cambridge
Jan. 1923.

The Physics of the Earth's Interior

H. Jeffreys. St. John's.

References to Laplace's & Planetesimal Theories.

1. J.H. Jeans: Monthly Notices. R.A.S. 77. p.186.
2. H Jeffreys: " " " 77. p.84

Ref. to Origin of Solar System

3. Jeans: Problems of Cosmogony.
4. Jeffreys: MNRAS. vol. 78. p.424.

Ref. 2. Possible Disturb^{ces} of Meteoric Bodies in Solar System.

Main objection to Chamberlin & Moulton's Planetesimal Thy. is that collisions of the small bodies wd. be so frequent & occur with such high vel. that the particles wd. be fused & volatilized long before accretion could produce any important effect on bodies as large as the planets.

Alternative hypothesis - original nebula assumed gaseous & perhaps highly heterogeneous, but constancy of angular momentum.

Summary of Laplace's hyp. & Moulton's 5 objections
" " C. & M.'s " of condensation around knots in arms of a spiral nebula. It obviates most of the objections to former Thy. but though allowing for retrograde satellites it wd. point to their being nearest the planet & not on the outside of its system as is the case

Saturn's Rings: Many collisions have resulted in symmetric orbits.

The Zodiacal Light - a broad luminous band surrounding Sun nearly in plane of ecliptic extending 90° from Sun & conspicuous betw. orbits of Merc & Venus. Believed to be due to light diffusely reflected or scattered by small ptcls revolving around sun - size uncertain meteoric or gaseous -

Ref. 1. The part played by Rotation in Cosmic Evolution

Summary of rotational disruption theories of Poincaré-Darwin (pear shaped fission) & Laplace-Roche (equatorial) His conclusion is that former gives binary stars & latter could only give a condensation of expelled matter into planets if parent mass were much gtr than Sun.

Ref. 4. Early Hist. of Solar System (Jeffreys)

Sustains idea of C. & M. that condensation was hurried & planets formed catastrophically by tidal disruption due to approach of heavy star. Proved dynamically possible by Jeans that the strea (or streams) shot out with considerable vel. wd be longitudinally unstable.

Effect of gaseous matter not at once collected into nuclei :- Probable reduction of planetary orbits giving data for estimate of age of Earth wh. agrees well with radioactivity estimate. Also resulted in small eccentricities of gt planets.

Moon is only satellite likely to have been less affected by resisting medium than by tidal friction

Any planet or sat. whose pres. diam is < 1000 km could never have been gaseous as its gravitative power wd not have held it together. Hence smaller members of system must have been liquid when formed.

Asteroids prob. formed by a primitive planet wh. approached Jup & was disrupted by tidal action

Moon is only sat. that can have been formed by tidal resonance. Since Saturn has no moon its density towards centre must exceed that of Earth

Mercury can never have rotated with the speed reqd for resonance & the action of solar tidal friction has been enough to keep it with same face to sun.

Venus rotation unknown. Mars too far out for intense tidal effect from Sun.

1/2/23. Previous argument that several planets were probably gaseous.

Chamberlain upholds a solid state for earth.

Thy. of Mt. Bldg by Elie de Beaumont.

Change of temp. results in contraction & hence crinkling up. Amt. does not agree with known vol. of mts.

∴ Chamberlain's alternative theory.

Mass of fragments of planetesimals on outside amounting to $\frac{1}{2}$ or $\frac{2}{3}$ mass of pres. earth. hence great compressive force on inside layers while outside layers are quite unstrained. Hence only available source of stress for mt. bldg arises after accretion has stopped & cooling commences. Loose structure gradually settles down & its interstices fill up consolidating surface layer. Forces involved do not explain mt. bldg. completely.

Fluid Earth theory.

1. Possible that our atmosphere did not exist then gases being in earth & coming out by volcanic action after solidification.
2. Could earth have held all this gas?

We know earth contains He. (mol. wt. 4)

Surface temp. averages 280° abs.

See Jeans Dyn. Thy of gases – last chap.

Shows that if $C = 72.5$ km/sec c = mean vel of mols. half atmosphere wd be lost in 2 million yrs.

H gives $C = 1.9$ km/sec.
+ is only just retained.

Consider H_2O at 1500° abs $C = 1.9\left(\frac{1500}{280} \times \frac{2}{16}\right)^{\frac{1}{2}}$
$= 1.5$ km/sec

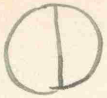
∴ a fluid earth could contain the water vapour + even more easily the N + O.

If a gaseous earth with 3 times present temp we still find it retains N + O.
∴ no difficulty from this pt. of view.

Planetesimal theory cannot provide atmosphere by meteorite infall since latter do not contain N or O

Adams (S. Kens) investigation of H_2O content of rocks.
Quite poss. all water vap in atmos has been expelled from interior of earth.
ditto pos. for N. (found in volcanic gases.
H
He
Contradictory evidence re O from volcanoes but it might quite possibly come from CO_2 by plant action.

Another criticism of fluid Earth Thy it would have been perfectly symmetrical (England centre of land hemisphere)
No satisfactory explanation.
Chamberlains Theory

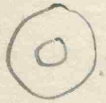


Random hits of planetesimals might result in more on one side than on other. (Why?)
Probability is $\frac{1}{2}$
Let m fall in one hemisphere + $n - m$ in other
Probability of this is ${}^{n}C_{m}\left(\frac{1}{2}\right)^{n-m}\left(\frac{1}{2}\right)^{m}$
This is max^m if $m = \frac{1}{2}n$.
Put $\frac{m}{n} = \frac{1}{2} + \xi$
+ above becomes. $\frac{2}{\xi} e^{-2n\xi^2}\sqrt{\frac{1}{2n\pi}}$.

Suppose planetesimals form layer 1000 km deep + average diam 1 km.
$n = 6000^3 - 5000^3 = 10^{11}$
+ if diff in height of 2 hemispheres is 1 in ~~½~~ 1000 i.e. $\xi = \frac{1}{1000}$.
∴ Probability is $2000\, e^{-2\, 10^{11}\left(\frac{1}{1000}\right)^2}\sqrt{\frac{1}{6\, 10^{11}}}$
$= 2000\, e^{-2\, 10^{5}}\sqrt{}$
= something distinctly small.

What is evidence that earth as a whole is composed of materials of varying densities.
Start with earth all uniform density.
inner portions are naturally much denser.
Mean density is 5.5
→ Surface rocks. about 3. Is increase due

only to compression?
Earthquake data give definite answer.
Elastic constants down to 3,600 km thus obtained



ρ = density.
p = pres.
r = dist from centre
V = gravitational potential

$$\frac{dV}{dr} = -g = \text{gravity}.$$

$$\frac{dp}{dr} = \rho \frac{dV}{dr} = -g\rho$$

Also $\frac{dp}{\partial\rho}$ measures compressibility.

$= k$ from th. of elast.

$= v_1^2 - \frac{4}{3} v_2^2 = 30 \times 10^{10} \frac{cm^2}{sec^2}$

v_1 = vel. of 1st earthquake wave.
v_2 = " " 2nd wave

Surface gives least value of these quantities.

Dividing eqns.

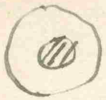
$$\frac{d\rho}{dr} = \frac{1000 \times 3}{30 \quad 10^{10}} = 10^{-8} \text{ surface value.}$$

Try depth = radius 6000 km.

$$\frac{d\rho}{dr} = 10^{-8} \times 6\, 10^{8} = 6.$$

$$\therefore \rho = 9$$

Hence to get average ~~as it is~~ consider



whole inner sphere has dens 8.2
+ radius ·78

and boundary 4·3.

+ mean dens. could not be as great as it is.

Hence we cannot consider Earth as homogeneous – but actually composed of a core of denser material than the surface layers –

[1740 – Comet Theory of Solar System Origin: In main essentials very like recent theory – if we substitute massive star for comet + near approach for impact].

Age of Earth.

Time to origin not pos.
Time to solidification of minerals is poss. by ratio of Ra to Ur in rocks – (Mme Curie 1898 Ra.
Ratio is 3.4 10^{-7} by weight –
Ra decays to $\frac{1}{2}$ in app. 2000 yrs. ∴ in rocks 10^6 yrs old how is there any Ra left –
∴ Decay of Ur – (proved by Soddy.
Rate indept of temp + pres.

Take block of ore with n atoms of Ur
r " " Ra
l " " other things.

$$\left.\begin{aligned} \frac{dn}{dt} &= -K_1 n \\ \frac{dr}{dt} &= K_1 n - K_2 r \\ \frac{dl}{dt} &= K_2 r \end{aligned}\right\}$$

① $\therefore n = n_0 e^{-K_1 t}$

② $r = \frac{n_0 K_1}{K_2 - K_1}\left(e^{-K_1 t} - e^{-K_2 t}\right)$

$K_2 = \frac{1}{2000 \text{ yrs}}$. (Known)

$\frac{K_1}{K_2}$ small. ∴ 2nd e term very small

∴ approx. $\frac{u}{r} = \frac{K_1}{K_2 - K_1} = 3 \times 10^{-7}$

K_1 is found to be $\frac{1}{6,600 \times 10^6}$ yrs.

Hence age of an ore.

8/2/23. Formation of He.

Ur. At. wt. 238.
Ra 226 } 3 α ptcls lost en route

Ra Em. A B C D E F

5 α ptcls lost & resultant element 206.4.

Nearest elements Bi. 208
Pb. 207.1
Th. 204.

Rt = 101.7.
Pd = 106.7
Rh = 102.9

If any of these were the final prod. of the radio active series it must be always present where there is Ur. Pb is the only one.

The Pb from radioactive minerals is 206.2 indistinguishable chemically from ordinary Pb.

Astons Isotope work explains this.

Thorium 232.

6 α ptcls given off before stability is attained. 208.0 shd. be last prod. Is it Bi. No for Bi is never found in Th. rocks while Pb is.

Pb in Th. minerals analysis gives high values for at. wt. but are never free from Ur or ord. Pb. hence never yet obtained pure.

K for Th. is $\frac{1}{19}10^9$ yrs.
for Ur $\frac{1}{66}10^9$.

Age determined by Boltwood by ratio of Ur Pb to Ur in 1907.

Took a no. of minerals of same geol. age.

Another method is by amt. of He in rock
Strutt (R.J.) 1908-10.

Both these methods have been used by A. Holmes.
Pb.-Ur method is the better.

1. Restriction on minerals used since there must be no Pb or He present initially
∴ use mineral with high Ur content so that Ur Pb will predominate & find the at. wt. at 206.2 not 207.

Usually Ur & Pb do not crystallize out together Ur is 6 valency & Pb 4 val.
also there is usually no He pres. originally

2. There must have been no disturbance since it crystallized
i.e. Products might have leaked out.

Effect of matamorphism after crystallization is to alter propns of Pb to Ur hence unsuitable for testing age.

Becker. (Am. J. of Sci.) based his unsound results on metamorphosed rocks. error shown by Holmes.

With He test – in powdering the rock to start with some gas is sure to be lost:
∴ He can only give a lower limit to age.
If rock has been exposed at surface some of the He will have escaped.

Results.	$\times 10^6$ yrs.	
Miocene	30	Based on Pb ratios
Eocene	70	
Permian	300	the He figures are less going up to 1000 10^6 yrs.
Carboniferous	330 – 360	
Devonian	380	
Pre Cambrian	900 — 1600	

These precambrian 1600 mil yr rocks are intruded into yet older sedimentary rocks. ∴ ocean is over 1600 10^6 yrs old.

Thorium ages not so satisfactory.
it is Tetraval ∴ liable to crystallize with Pb.
Best Th minerals are usually metamorphosed
∴ unreliable.

Ref: A Holmes: The Age of the Earth. 1913.
Discovery – Apr. 1920. for later results.

The geological Method based on rate of denudation – i.e. amt. of salt taken to sea. or rate of deposition of sediments.
In latter case difficulties due to same sedimentary material being used over & over again. i.e. sediments on land areas –

Holmes tries to base his estimate on deposits coming only from igneous rocks.
His corrected value is 3.5 10^8 yrs –

J. Joly on Sea salt 1.26×10^{16} tons Na in ocean now. 1.56 10^8 tons taken down annually by rivers
∴ age of ocean 80 10^6 yrs –
Difficulty due to Cl in ~~ocean~~ rivers being only 38 10^6 tons. Amt of Na reqd to combine with it wd be. 87 10^6 tons. Hence 49 10^6 tons excess Na.

Another difficulty due to K in sea in very small quantities though in rivers amt. is comparable to that of Na.

All the geological estimates average out at 3 10^8 yrs.

These based on assumption of present rate of denudation existed always.
Evidence is that rate is greater now due to recent glacial period.

Rate of denudation is a function of slope (6th power ?) i.e. height of land areas.

Assume that pres. rate is 5 × average rate of denudation & results compare well with Ra method
Between Eocene & Permian just before gt period of mt bldg. there could have been very little denudation.

Kelvins method.
Contraction of Sun. velocity of infall of its external particles results in formation of heat. Energy from its gtst possible drain to pres. size at pres. rate of radiation would last 20 10^6 yrs.
Out of date due to radioactivity knowledg
But it rests on princ of Cons. of Energy. This is Helmholtz theory of Suns heat

But we must discover another source.
Eddington has shown from Cepheid variabl

δ Cephei. density should increase 1% in 40 yrs. if its energy supplied only by contraction.
Period of its expansion & contraction should theoretically vary as density.
∴ Period should decrease 1 sec in 80 years.
This change has not been detected.
if there be a change it is $< \frac{1}{400}$" in 80 yrs
∴ there is some source of energy for these stars other than contraction.

If Kelvins estimate be mult. by Eddingtons actual factor it gives 800 10^6 yrs.

15/2/23

K.E. due to disintegrating Rad-act atoms results in heating effect.
Measured by means of vel. & no. of α ptcls emitted.
Also heat due to β & γ.
Ur. (total effect) 8.0 10^{-5} cal/gm hour.
Alternative method. Dewar flask filled with pitchblend. Excess temp measured.
Poole found 0.007°C. diff of temp. corresponding to 12.8×10^{-5} cal/gm hr.
This method not considered so accurate.
upper limit. possible chem. change heat

Though small this heat is of gt. importance in Earth.

Types of rock.	Ur. (gms/gm. Rock).	Th. ( )	Heat produced. Cal/gm. hour Ur.	Th.	Total.
Igneous					
Acid	·91 10^{-5}	2.9 10^{-5}	×7. 10^{-10}	8 10^{-10}	15. 10^{-10}
Intermed	·61	1.7	4.5	4.6	9.
Basic	·30	0.5	2.3	1.3	3.6

Note that Tho more Th. not so active
" " . acid rocks more heat than basic.
This is important.

Put into Cal/cc. sec.
Acid. 1.03 10^{-12}
Basic 0.29 "

Heat gradient at surface can be calculated
K = Thermal conductivity. x = depth.
V = temp
$\left(k \frac{dV}{dx}\right)$ = rate of escape of heat
$K = \cdot 00669$
$\frac{\partial V}{dx} = \cdot 00032$ Product $= 1.9\ 10^{-6}$ cal/cm² sec.

This means that 19 Km thickness of acid rock at surface wd produce this heat & thus account for the whole of the heat conducted from Earth
If rocks below were equally radioactive earth wd. be getting hotter inside

If we are assuming a fluid Earth.
we can imagine its temp constant but not rising.

It cannot ∴ be the fact that the rad. act. remains the same to 19 Km.
Geol. evidence goes to show more basic as depth is increased
∴ less rad. act.

Rate of falling off of rad. act is completely unknown. but suppose an exp^l. law.
A = evolution of heat per unit vol.
Put $A = A_0 e^{-ax}$
A_0 = surface value. a a constant
x depth.

$$\frac{\partial V}{\partial t} - \frac{k}{c\rho}\frac{\partial^2 V}{\partial x^2} = \frac{A}{c\rho}$$

is the diff^l. eq^n. satisfied by temp. Assume proof.

t = time
V = temp
c = spec. heat
ρ = density.
put $\frac{k}{c\rho} = h^2$.

If earth originally fluid temp at any depth is melting pt of the rocks at that depth

1st effect of solidification contraction & gtr density. cools breaks up & sinks.

∴ Temp = melting pt + extra heat due to compression on way down.
(cf. air in bicycle pump)

$V_{t=0} = S + mx$ $\quad$ V = initial temp when $t=0$
= S (melting pt) + term due to depth & compression

$$V = mx + \left(S - \frac{A}{a^2 k}\right)\frac{2}{\sqrt{\pi}}\int_0^{x/2h\sqrt{t}} e^{-u^2}\,du + \frac{A}{a^2 k}\left(1 - e^{-ax}\right)$$

See Ingersols Phys of Heat.
Phil Mag 1917
H Jeffreys

diff. by x.

$$\frac{\partial V}{\partial x} = m + \frac{S}{h\sqrt{\pi t}} + \frac{A}{ak}\left(1 - \frac{1}{ah\sqrt{t}}\right) \quad ⒤$$

a is only unknown.
m not well known - certainly < .00002
S = melting pt. of surface rocks 1200°C
I = time since earth solidified approx.
= $1.6\ 10^9$ years. = $5\ 10^{16}$ sec.
k for average rock .005
ρ = 2.8
c = 0.25

This gives h = 0.084.
Quadratic Eqn to determine a.

One root comes out neg.
Take other root.
Root gives $a = \frac{1}{15}$ km.

i.e. at $\overset{15}{\cancel{10}}$ Km rad. act. has fallen off to $\frac{1}{2}$ its surface value.
This result seems to accord well.

Basic rocks about $\frac{1}{4}$ as active as acid
∴ above result implies basic region at 20 km.
Confirmed by basic lavas from gt depths.

On other hand below ocean a diff.
measured values have all been in mines etc. no data for ocean bottoms or deep boring in oceanic islands.
But geol. evidence that rocks of ocean floor almost entirely basic.
No solution for problem as to why the acid rocks are confined to the continents.

Hence assume radioact. condns of ocean floor more similar to conditions of basic rocks. i.e. value of A for basic rocks.

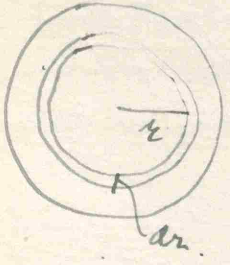
Thus infer that temp under oceans has fallen more since solidification than temp under continents since less rad. act. tending to heat up.

If we take eq^n (iii) values are —

$.00032 = .00002 + .00006 + .0002$

$\frac{3}{4}$ of effect is due to rad. act. (last term)

$\frac{1}{5}$ to cooling in ord. sense.



Consider thin layer inside earth — dist r from centre thickness dr. Suppose its temp rises by v

Vol. $4\pi r^2 dr$

α = coef. of linear expansion —

Inc. of vol. is $4\pi r^2 dr(1+3\alpha v)$

new vol. of whole region originally of radius r is $\int_0^r 4\pi r^2 dr(1+3\alpha v)$

If symmetry retained — new radius is r'

then $\frac{4}{3}\pi r'^3 = \int_0^r 4\pi r^2 dr(1+3\alpha v)$

r' very nearly r. $r' = r + \frac{1}{r^2}\int r^2(3\alpha v)dr$

i.e. $r' = r(1+\alpha v)$ approx.

if symmetrical expansion.

these 2 eq^{ns} should equal.

but if former vol. too great there is crumpling up & bulging

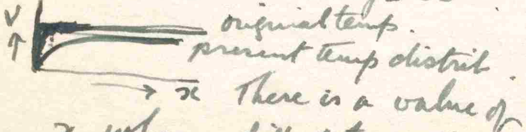
if too small there is stretching & consequent fractures.

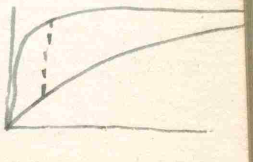
actually it appears there is crumpling not stretching.

$$\frac{1}{r^2}\int_0^a \alpha v \, dr^3 - r\alpha v = \frac{1}{r^2}\int r^3 d(\alpha v)$$

Integrating by parts

By hypothesis no change of temp at centre or surface





There is a value of x where diff of temp is maximum. this is near outer part. & ∴ the increase of temp on inside makes the vol. too great - ∴ there is crumpling.

This amounts to a reduction in surface of land

Land 1.45 10^8 Km^2
Sea 3.7 10^8 Kms^2.
Total 5.1 10^8 Km^2. reduction.

Compression of Rockies, Appal. + Cascade has been made. also Himalayas (by Oldham - 120 km loss at rt. angles to axis of range after mts were formed) Value for Alps differ gtly - none for other gt. mt. ranges -

Estimate 1.9 10^8 Km - for all

Hence it is evident that the above source of contraction is amply sufficient to meet the observed amount.

22/3/23 Correcting above figures.
Available on theory Land 1.1 10^6 km^2
Sea 3.8 10^6 "
Reqd amt. 1.9 10^6

Note - all mts are on land.
& this alone not sufficient.

But consider deeper contraction -
gtr cooling under oceans due to less radioact.

Even if at same temp. basic rocks on the whole stronger than acidic. ∴ in general rocks under ocean stronger that at equal posn under continent.

Consider stress. 

contraction inside ∴ this layer is too large. + continent portion gives way first. & is folded & a thrust from ocean towards continent.
∴ get mt range just inside continent + ||le to coast. e.g. Rockies Cascades Andes -
Hence reduction in surface of these mts arises from compression from ocean bottom.
for these mts - amt of compression
Pacific type. ·6 × 10^6
∴ 1.9 - ·6 = 1.3 to be accounted for by compres. of continents -
+ estimate is 1.1
∴ Theory is considered satisfactory

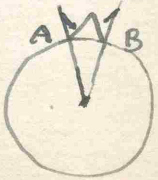
There are other causes of mt. bldg. but
this one cannot be ignored.

Summary..

1. Dynamical considerations require
tidal theory.
gaseous planets -
passing thro liquid to solid stage.
2. Age of Earth - indep^t evidence
of thermal cond^ns & radio act. heat.
3. Applying facts + theories of (2)
we have accounted for mt. ranges.
& seen that there are 2 types.
(1) Pacific type. ||^l to coast line.
(2) Continental type dir^n indep^t. of coast line

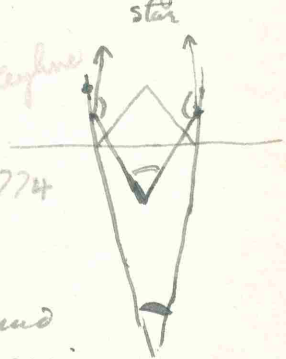
Further progress requires theory of
Isostacy.

Old idea. Mts composed of same materials
+ of same density as surroundings.
This assumption was basis of first measurement
of ~~[illegible]~~ G.



Pendulum deflected in towards
mt. from line to centre of earth.
take bearings to a fixed star
from A + B. + hence get angle of incl.
of pendulums.

Knowing radius of earth + angle.
the angle ϖ is found
+ hence G.

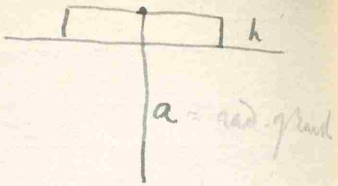


(Maskelyne

1st Mt. Schehallion in Perth. 1774
2nd Repeated in Peru
for a large mt.
+ deflection was found
less that was expected using
the value of G found by Cavendish
method
This was found by Boug~~ieres~~ uer
+ Condamine 1749.
Repeated by Petit at Pyrenees
+ a repulsion instead of attr^n
was found.

∴ Not sufficient to consider only attr^n
of mass of mt above av. level of land.
but also deeper parts which partly
compensate by having a density
less than average -

Consider a plateau
of ht. h above
surrounding level.
Gravity at a pt.



Mass of Earth $E = \frac{4}{3}\pi a^3 \bar{\rho}$

Const of grav. f mass of earth E

gravity at surface g
mean dens. of earth $\bar{\rho}$

$$g_0 = f\frac{E}{a^2} = \frac{4}{3} f \pi a \bar{\rho}$$

$$g_h = f\,E/\overline{a+h}^{\,2}$$ due to whole earth but not plateau

$$+ 2\pi f \rho h$$ due to plateau of dens ρ.

$$= g_0\left(1 - \frac{2h}{a}\right) + 2\pi f \rho h$$

$$= g_0 + \frac{g_0 f}{a}\left(-2 + \frac{3}{2}\frac{\rho}{\bar{\rho}}\right)$$ Bouguer

In actual cases ^ is always too large.

Alternative formula of <u>Helmert</u>

$$g = g_0 - \frac{2 g_0 h}{a}$$

i.e. instead of plateau attracting it acts as a shell merely raising pt further from centre of earth.

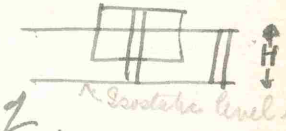
This is an improvement but not sufficient
actual value lies between the B & the H. formula.

Theory to account for this due to
Pratt 1885 - revived by Dutton 1889.

Mt. assumed to have density of surrounding
but beneath it is lighter material.

H

A smooth surface corresp. to equipot. surface. then colums of equal cross section contain same mass



i.e. Mt. a lighter mass floating in denser medium - Compensation theory.

Precise form of theory due to Hayford (U.S. Geodetic Survey).

Depth

Below a certain depth all surfaces of equal pres. & density coincide.
i.e. distrib of dens. is same as you wd. get in a liquid rotating as is Earth
True from centre out to about 100 km below surface.
Average depth of this surface. H.

This gives values of gravity between B & H.

By adjusting H. exact value of g on a mt-top can be accounted for.

Theory must also stand test of hilly but not mtous. country, valley, coastal regions: etc.

This has been attempted by US. Survey.

	B.	H.	Hayford. H = 114	H = 60
Coast.				
Mountains	0.021	.022	018	017
Valleys	.111	.059	017	022
Among mts.	.108	.024	.020	018

Residuals (pos. or negative)

Units - 1 cm/sec⁻²

g = 981.xyz

1. In every case Hayford has a smaller discrepancy than either of others but he has the extra constant to adjust.

2. Note at low levels Hayford not appreciably better than B & H. but on mts. it is much better. & for valleys.

Hence Hayfords assumption is strongly justified.

Ref Barry. US. Survey. Values of gravity & Isostasy 1917.

Considering sign of residuals (mean)

B	H	Hayford. 1.	2.
-.110	+.056	+.001	+.016

Hence strong evidence for the approximate truth of Hayford Thy.

Similar test - considering dirn of gravity instead of intensity - to determine H. Close agreement.

To account for intens of g H = 95 km

" " " dirn " " H = 97 km.

Results as far as obtained for India & Europe are in fair agreement.

Geophysics problem is why, when a mt range is elevated, this defect of density occurs below.

Answered by Thy of Equilibrium of Earth.

Cooling spreads down from surface.

~~Ford~~ Relation of change of temp & time & depth shows at depth of 400 Km. practically no change of temp since solidification.

Crumpling at
surface rocks
(lighter rocks)

weak region in
interior.

they are broken & sink into interior
+ weak region gives way until
again surface of equal pres +
equal dens. are the same.
leaving this excess of lighter rocks
from surface downward

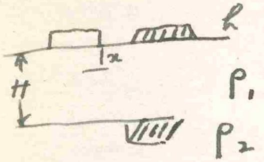
1/3/23 Copied from G.V.H.

Ref. Sir Sidney Burrard – India. Geog. Journal
Geol. Mag. July 1920 – Davies.
Jos. Barrell (Harvard) J. of Geol. 1915-16.
Special ref. to Niger △ – no faulting
around margin.

There may be expansion due to chem
action taking place but this is not
proven physically.

Bowie Am. J. Sci. 1921.

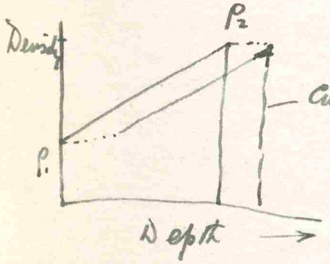
Jeffrey's suggestion: That the density below
increases to take up the wt. above.



$\frac{\rho_1 h}{\rho_2}$ –

$h - \frac{\rho_1 h}{\rho_2}$

$$\rho = \rho_1 + (\rho_2 - \rho_1)\frac{x}{H}$$



Curve shoved over due to
loading.

Assumption that below the density
increases with depth.

Hills as small as 600 metres in ht.
are compensated.

Asthenosphere or lower layer.
$\frac{1}{\pi}$ × extent of compensated region.

Place	Height	Bouguer	Hayford
B'ham (Ala)	179 m	-0.034	-0.030
Duluth	216	+0.025	+0.049
Winston-Salem	284	-0.049	-0.034

Some residuals 0.020 $\mathrm{cm}/\mathrm{sec}^2$

formula $\frac{2gh}{a}\left(1-\frac{3}{4}\,\frac{\rho'}{\rho_0}\right)$

$$= \frac{2000\,h}{6\times10^8}\,\frac{5}{8} = 0.020$$

or $h = 10\,000$ cm

The granitic rocks are more radioactive than the basic ones & consequently will contract more

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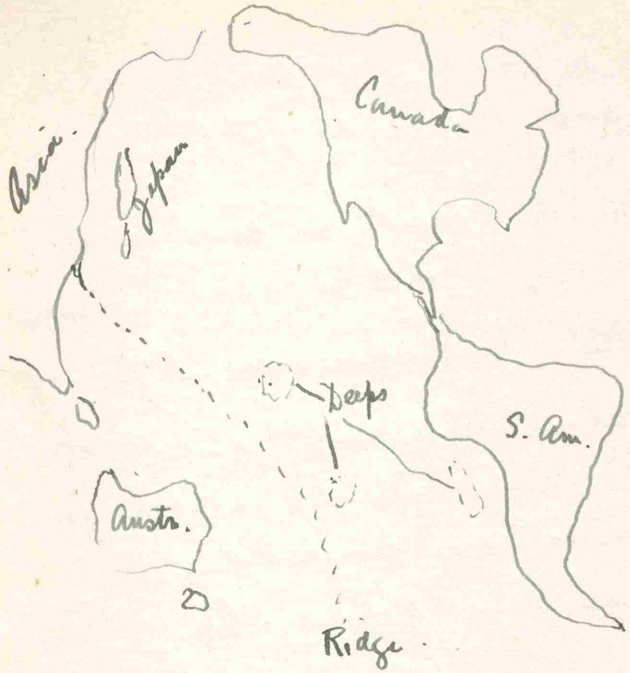
Curvature of ocean bottom

Curling effect due to dehydration of the layer below the Ocean



Mountain Bldg. Two problems must be solved.

See Morley Davis Geol Mag. 1920

This may be an original deep & not quite compensated & filled with sediments

Note on how to find pull or lack of pull due to a Mt.

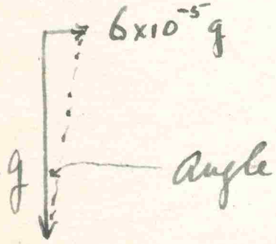
Take a transit + level it by means of a dish of Hg. Latter is <u>not</u> quite level due to the Mt. Select a star fairly near horizon + one fairly high up whose times of transit are tabulated - Note diff in time with a stop watch between their transits - the excess or deficiency of a few seconds is due to the error in levelling Hence find this error

Consider. Tristan da Cunha.

$$\frac{fM}{r^2} = \frac{6\times10^{-8}\times3\times\pi\times(7\times10^5)^2\times10^5}{(7\ 10^5)^2}$$

$$= 6\times10^{-2}\ \text{cm/sec}^2.$$

$= \text{approx. } 6\times10^{-5} \text{ of } g.$



angle approx. 12''
wh. is quite measurable.

where 6×10^{-8} = grav-const = f
3 = av. density of surface rocks!

10^5 = height of island in cm
= 1 [illegible] km = ·6 mile = 3000 ft

7×10^5 = radius of island
= 7 km = $4\frac{1}{3}$ miles.

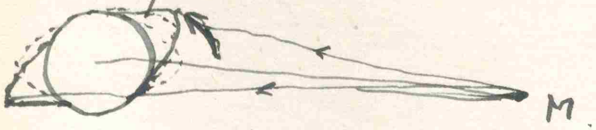
2 Problems.

1. Origin of Continents
2. Cause of Intrusion.

2. As yet no means has been suggested for accounting for horiz. tension capable of rupturing a rock.

1. Most satisfactory theory

Tidal friction



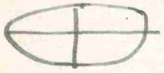
With rotation tide is carried round instead of being towards moon. Protuberance pulls moon along ← + also ← former is greater

∴ resultant force on moon is ↑

Assume Conservn of Ang. Mom.

∴ Moon tends to exert force on Earth ↓ i.e. rate of rotation of earth getting slower. This amt. can be observed.

1.6 10^9 yrs. ago ~~Rate~~ Time of rotation 10 hours.



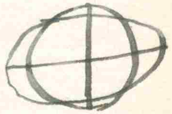
Eccentricity & period of rotation.

∴ when at 10 hours.

(present ecc. $\frac{1}{295}$)

$$ecc = \frac{1}{295} \times \left(\frac{24}{10}\right)^2 = \frac{1}{50}$$

Since then polar regions have extended + equator contracted



Diff. betw polar & eq. radii now is 20 km.

∴ Change since geol. times 5 times that – i.e. 100 km

100 π = 600 km.

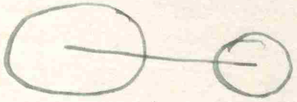
Hence change along ~~meridian~~ equator
is half this = 300
& this is the amt of compression
at eq.

At polar it is not available
why ?

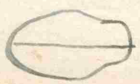
This must account for Mt. bldg.

Origin of Continents

Effect of accel on Moon makes to
go further away
∴ once it was very close
Somewhat this scale.

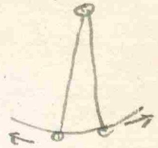


Just befor this earth & moon
formed one body.



Resonance Theory of Rupture

no limit to size of amplitude
that can be attained.



Consider Spherical earth.
oscillation sets up
period about 4 or 5 hours.

Cons. of Ang. Mom. gives rate of
rotation when E. & M one body
& Sun wd have a tidal
projn towards & from it.
& the period betw successive
tides wd. be ½ period of
rotation i.e. 2½ hrs.

Period of natural oscilln wd be
about the same.
Then ellipticity wd. keep increasing

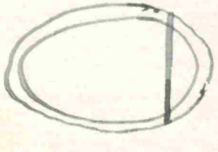
& so no limit to extension possible

Probably at some stage a slight
disturbance was set up & rupture
at a place | follows.

Difficulty may be in the great size of the ruptured part. but it does account for Ang. mom. as at present & for fact that the small earth has the heaviest & only really large satellite.

Osmond Fisher's theory that when rupture came earth was partially solidified, thin crust wh. wd not affect the resonance much since its rigidity wd not hinder a resonance of such slow period as this.

O. F. says Moon came from part of crust nearest Sun



i.e. no outer crust over new surface

i.e. ocean bottom left - now bottom of Pacific.

This help to account for the lob-sided topography of Earth.

But difficulties are (1) while agitation was going on the strength of the remaining crust wd have been rendered apart & torn & wd have redistributed themselves as symmetrically as pos. within a few hours.

(2) On Mars a similar asymmetry exists but no satellite has been produced by Mars. ∴ the thy accounting for Mars might apply to Earth.

However Res. Thy. is the only one wh fits so many facts & seems possible ∴ worth considering.

One curious pt. Moon wd be of

crust ∴ should contain large prop^{n} of radio act. matter

∴ tendency to heat up + expand

note that on Moon there are no folded mts. i.e. surface is in tension as though expanded. whereas Earth is in compression.

Glaciation on Earth.

Most of Europe + N. Am., during last period, under thick ice sheet - ended 20 000 yrs ago

Another period in Permian period 300 000000 yrs ago.

In Pre Camb. another period. very great 1000,000,000 yrs ago.

In between them have been occas. local glaciations

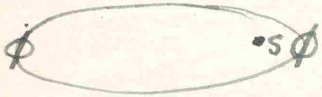
Between gt. periods are long periods of equable climate esp. after Pre Camb.

i.e. 2^{ndary} + Tertiary ages.

Hypotheses are many to account for glaciation.

Classified thus:-

1. Changes in motion of earth as a whole.



Earths orbit - very eccentric, incl^{n} of axis brings N. Pole at aphelion + summer coincides with lowest heat receipt. ∴ diff. between summer + winter not very gt.

Whereas S. has reverse very severe climate. summer short + hot but not hot enough to melt ice from long cold winter

Dr Croll suggest glaciation when orbital ecc. at its max^{m}.

If earths axis $\perp^r$ to ecliptic we
get no summer + no winter.
∴ suggestion that inclination
of axis is the governing factor

Objections (1) There have been
too many glacial periods
Changes of ecc. arise from attraction ~~posns~~
of planets also incl^n of axis
but attr^n of planets is a very
regular thing. producing
very long period variations
of about 2 000 000 yrs.
∴ glaciation periods shd. be
of same period
∴ there shd have been 5 in
the time in wh. only 2.

(2) Variation in Internal heat
of Earth.
From Earths conductivity + heat
$.006 = K$
gradient $\left(\frac{\partial V}{\partial x}\right)_{\text{inwards}} = .00033.$

$K\frac{\partial V}{\partial x} = 2\times10^{-6}$ cal/cm^2 sec
is outflow of heat.

Solar rad^n const. $= 3\times10^{-2}$ cal/cm^2 sec

i.e. 15 000 times as much
heat is recd from sun as from
centre of earth.
∴ impos that internal cond^ns
could bring about a glaciation
period.

(3) Changes in Compos^{n} of Atmosphere

+ in Compos^{n} of Ocean.

i.e. 1. Variations in amt of Volc. Dust
2. " " " " CO_2

1. Some support from changes in weather after Krakatoa 188-
+ Mt
in Alask. 1912.

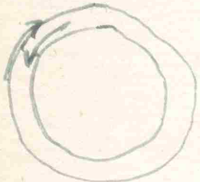
but E. Huntington has pointed out that last glac. period extended for such a time that 75 Krakatoa's wd be necessary & their marks wd be visible (wh- they are not.)

2. CO_2 theory untenable since the heat absorbed by CO_2 might equally well be absorbed by H_2O vap. wh was always present.

3. Variations in Salt in Sea.
Chamberlain argues that

lower dens at eq. by thermal expans- sets up circul^{n} of oceanic waters towards Poles.

+ in early times oceanic waters were more saline, evap. over equator causes gtr salinity ∴ gtr density at equator region ∴ circulation wd be in opp. dir^{n}.



+ influence on climate very considerable.

Objection General circulation not dependent on density but on wind wh. wd. cause currents as before

(4) Refs. 1. E. Huntington + S.S. Visher
Climatic Changes. 1923.
2. C.E.P. Brooks – Evolution of Climate – 1923.

1. Depends on changes in Rad^{n} of Sun

2. depends on changes in form of earths surface.

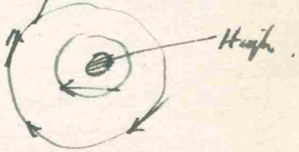
Both have probably a great influence. Doubtful if latter alone is sufficient.
Former takes latter & accounts for the things not explained by it by his additional hypothesis of variability of Sun.

Last Lecture 13.3.23.
copied from G.V.D.

C.P. Brooks: Take a pt. on Earth & draw ⊙ 800 nautical miles radius & record % land & % water. Do this for every 20° of latitude. He gets thus a series of spots about the lines of Lat & draws comparisons - quantitative results.
Cold to windward has a greater effect than cold to leeward.
His conclusions coincide with the work of geologists.

In the Tertiary land on the whole was rising.

Temp gets lower going up - takes in more heat on the lee side of mt. than it lost on other side.
The ice will keep piling up on the lee side of the mts.



Wegener
Centres of glaciation

The Huntingdon Theory (1) amounts to this that the Sun is a variable star.

High sunspots coincide with high pressure

(G.V.D. note: Examine lunar face for reflection of ice.)

Action of Jupiter on the Sun

α Centauri was 2/3 of its present distance 28000 yrs ago. This was the age of glaciation. Sirius will be near Sun in 68000 yrs.

End of Jeffreys Lectures.

References obtained by G.V.D. 1921.

Osmond Fisher – Physics of Earths Crust.
Dutton. Phil. Soc. Wash. Bul. Vol. 2. 1889.

Expansion of crystals & mountain raising
Eclogite → gabro means expansion.
Density of gneiss 2.7 – 3.3 variation in volume.

Chamberlain. Proc. Am. Phil Soc. "Interior of the Earth". 1915.

Isostacy "hydrostatic equilibrium with the water squeezed out & the equilibrium somewhat doubtful."

Undertow. see Col. Tandy on Subterranean circulation. R. Geog. Journal March 1920.

No flow of rock at base of Tibet Plateau.

All the above referred to in article by Col. Sir Sydney Burrard. Geog. Journal Vol. LV. 3. Sept. 1921

Rel F. E. Wright -

Wegener Hyp. & Origin of the Oceans.

Nature. Feb 24 /23 . p 253 .

(T. Crook)

Ref. to Osmond Fisher (1882 or later)

Physics of the Earths Crust.

Moon from Pacific left hole wh. drifted continents wh had split into a gtr & lesser part leaving rupture between - "Newly exposed ~~molten~~ surface of molten Substratum again solidified, a fresh Crust of greater density than before wd be formed out of the heavy Substratum over middle of area & also ~~with the~~ channels between the fragments wh had floated away Atlantic being chief of those channels"!!

miles

miles

ocean

be

ly-

r

as

d.

analogous to volc. eruption [illegible] [illegible].

W H Pickering 1907
"Place of Origin of Moon — the
Volcanic Problem —"
forestalled Wegener

F. B. Taylor – 1910
Bearing of the Tertiary Mt. Belt
on the Origin of Earth's Plan.
Drift of N. Am. from Greenland not v.v.

Ref. F. E. Wright.
Sci. Monthly May 1927
Gravity on Earth + Moon.

good summary of Isostacy theories.
+ g- methods.

gravity on moon $\frac{1}{6}$th g on earth

∴ a 75 mm gun on earth range 5.1 to 8.5 miles
on moon " 230 to 280 miles

Big Bertha 75 miles on earth
2,250 miles on moon = $\frac{1}{4}$ circum

muzzle velocity 1 mi. per second.

Hence with same volcanic muzzle vel. debris from lunar craters wd. be hurled far + wide so that similarity to terrestrial craters is not to be expected

Regarding meteoric theory the circular shape of craters doesn't disprove it as even oblique meteors with velocities undiminished by any atmosphere wd. penetrate lunar surface + generate so much heat ($= \frac{1}{2}mv^2$) that an explosion analogous to volc. eruption would result.