AN ANALYSIS
OF
SHIP AIR AND ITS EFFECTS.

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To isolate and clearly define those adverse agencies which oppose health and longevity is obviously the first step towards their amelioration or removal. Although the vitiation of ship air has been long recognised, and ventilation is not unattended to either in the construction or after management of ships, the following observations will go far to show that their ventilation is still imperfect, and ship air more impure than commonly supposed. We know exactly the contamination of what the landsman and soldier breathe, and ventilate their abodes accordingly. But we have yet little else to indicate how much, or by what, ship air is polluted, beyond such unsatisfactory phrases as foul, close, &c. Facts form the surest criterion of where and to

what extent hygienic reform is necessary. Without an analysis we are working, so to speak, in the dark. To prove how vitiated ship air may become, and thereby show how necessary thorough ventilation is, is therefore an important preliminary toward giving seamen a healthier atmosphere.*

Ship air is more impure than barrack and house air, because—

I. Immersion complicates ship ventilation ; preventing it below and often at the sides.

II. Many handicrafts are unavoidably carried on and stores kept, so to speak, in the midst of the crew.

III. The men are berthed and stores kept in the centre and lower parts, *i. e.* those most difficult to ventilate.

IV. And chiefly from overcrowding. While the soldier has, at least, 600 cubic feet of sleeping room, and from 1500 to 1800 in the tropics, an increase to 3000 feet being recommended,† Table I, giving the average air space and distribution of the men in a frigate, the type of a large part of H.M. and other navies, shows—

1st. That although the uncurtailed internal capacity would give her crew of 600 an average of 576 cubic feet per man, the crew proper really have no more than 63 on the densely crowded lower deck at meals, and from 105 to 222 at night on the sleeping decks where the hammocks usually touch.

2nd. That each cadet has only 100 cubic feet at meals, 117 at study, and from 242 to 506 at night.

3rd. That each ward-room officer has only from 300 to 400 cubic feet.

4th. That the allotted space is the same in all climates.

* Cannot the barometer, and other apparatus for indicating the physical condition of the air, be supplemented by some instrument to show at a glance the degree and nature of its impurity, without having recourse to the more difficult and tedious processes of analysis ?

† Parkes, 'Practical Hygiene.'

TABLE I.—*Distribution of men and average air space (H = harbour ; S = sea).*

Place.	Number of men.		Total cubic space in feet.		Average cubic space per man in feet, corrected for bodies and bedding.	
	Night.	Day.	Night.	Day.	Night.	Day.
Entire ship	H 600	H 600	H 345,637	H 345,637	H 576	H 576*
{ Before steerage	S 600	S 600	S 345,637	S 345,637	S 576	S 576
{ Steerage (cabins included)	H 44	H 500	H 31,548	H 29,948	H 105	H 63
{ Steerage (cabins included)	S 200	S 500	S 32,348	S 29,948	S 161	S 63
{ Cockpit	H 8	...	H 14,676	...	H 333	...
{ Cockpit	S 44	...	S 14,676	...	S 333	...
{ Ward room	H 8	...	H 2,053	...	H 257	...
{ Ward room	S 7	H 30	S 2,053	H 3,505	S 257	H 116
{ Chest room	H 26	S 30	...	S 3,505	...	S 116
{ Chest room	S 26	...	H 6,700	...	H 242	...
{ Lower deck (entire)	H 285	H 600	H 66,709	H 64,989	H 237	H 108
{ Lower deck (entire)	S 385	S 600	S 66,709	S 64,989	S 173	S 108
{ In front of office	H 192	...	H 41,251	...	H 222	...
{ In front of office	S 292	...	S 40,451	...	S 138	...
{ Half deck (cabins included)	H 15	...	H 11,760	...	H 784	...
{ Half deck (cabins included)	S 15	...	S 11,760	...	S 784	...
{ Study	H 8	H 34	H 4,049	...	H 506	H 117
{ Study	S 8	S 34	S 4,049	...	S 506	S 117
{ Gun room (cadets)	H 0	H 72	At meals.	...	...	H 100
{ Gun room (cadets)	S 0	S 72	...	H 7,248	...	S 100
{ Main deck (entire)	H 215	...	H 64,404	...	H 299	...
{ Main deck (entire)	S 315	...	S 63,604	...	S 201	...
{ Store rooms	H 0	...	H 0	...	S 480	...
{ Store rooms	S 8	...	S 3,830	...	...	H 120
{ Cells	H 1	...	H 120	H 120	H 120	S 120
{ Cells	S 1	...	S 120	S 120	S 120	S 120
{ Cabins on lower deck	H 1	...	H 300	...	H 300	...
{ Cabins on lower deck	S 1	...	S 300	...	S 300	...
{ Cabins on main deck	H 1	...	H 432	...	H 400	...
{ Cabins on main deck	S 1	...	S 432	...	S 400	...

* If corrected for engines, stores, &c., these averages would be reduced to 450 cubic feet.

† This term corresponds with floor or flat, and must not be confounded with the hold "tiers," where spare sails, &c., are kept.

The usual impurities of ship air are of animal, vegetable, and mineral origin, and comprise odorous and inodorous gases, vapours, and solids, all more or less unhealthy, and derived—

1st and chiefly, from the skin, lungs, &c., of the crew, which yield carbonic acid, ammonia, sulphuretted hydrogen, volatile organic matter, watery vapour, &c.

2nd. From the ship,—organic and inorganic odours, and minute particles of wood, paint, cordage, whitewash, leather, iron, brass, &c.; from the bilge and lining—ammonia, sulphide of ammonium, sulphuretted hydrogen, and occasionally microscopic animal and vegetable organisms.

3rd. From the stores,—particles of bread, cotton, wool, &c.; from the slow combustion of coal in the bunkers, perhaps carbonic acid and carbonic oxide; from the rapid combustion of coal, candles, oil, &c., these gases and soot, sulphurous acid, sulphuretted hydrogen, ammonia, sulphide of ammonium (Parkes); from cooking,—volatile, animal, and vegetable odours.

4th. From gun firing,—carbonic acid, carbonic oxide, hydrogen, sulphuretted hydrogen, suspended salts (Parkes).

5th. From sea spray,—salts, and moisture.

The following analysis of the air of the wooden screw-frigate *Bristol* (ventilated chiefly on the old windsail plan), made during a four months' voyage (July to November, 1871) from the Cape of Good Hope to England, represents that of a class of ship still large and likely to remain so. In modern ironclads the impurity probably does not differ much from this either in nature or extent. Less sulphuretted hydrogen, doubtless, emanates from an iron than from a wooden bilge; but other impurities may be added, and the chief ones, carbonic acid and organic matter, are probably not materially if at all lessened. Because, although greater size and comparatively smaller crews give a larger average air space, and modern ventilation favours purity, they have smaller ports, are altogether more closed in, and thus admit pure and emit foul air less freely; especially deeply immersed ships of the turret-and-ram class.

The degree of impurity doubtless varies. In some ships it may be more, in others less than this. But there is reason to believe that in all it is higher than usually suspected, and than it ought to be. In those merchant vessels in which the men are dirtier, more crowded, and the ventilation bad, the vitiation is doubtless still greater.

1. *Carbonic acid.*

The results of 150 analyses prove that this is the most abundant and important impurity; and Table II of 111 by Pettenkofer's test* shows—

1st. That ships throughout are, at all times and in different degrees of crowding, pervaded and, doubtless to a certain extent, enveloped by an atmosphere containing from 4.20 to 33.71, average 14.60 volumes of CO_2 per 1000,† the oxygen in the air being, of course, correspondingly diminished.

2nd. That this gas is most abundant, and varies from 4.20 to 28.85 volumes, when and where there is most crowding, *e.g.* on the lower deck and middle tiers, at meals and by night; proving that respiration, pulmonary and cutaneous, is its chief source.

3rd. That owing to diffusion, direct vitiation from combustion, the bilge, &c., and difficult, therefore imperfect, ventilation, the lower parts generally, show from 9.34 to 26.37 volumes.

* The size of the glass bottle employed was 215 fl. oz. (or 372 cubic inches), an ordinary bellows being used to charge it. The solution of oxalic acid to test the aqua calcis before and after its contact with the air was of the usual strength, *viz.* 2.25 grammes to one litre of water. The aqua calcis usually contained from 20 to 30 milligrammes per 30 cubic centimètres. The strength mentioned by Parkes (34 to 39 milligrammes) is more apt than a weaker one, from change of temperature and evaporation, to leave a deposit of hydrate of lime on the sides of the bottle, thus interfering with results. The lime water and air were kept in contact from ten to twelve hours. The subsequent calculation was that detailed in Parkes's 'Practical Hygiene.'

† This and other gases are reckoned throughout at so many volumes per 1000.

4th. That, both from direct vitiation and diffusion, the more open, better ventilated, and less crowded main deck tier contains from 4·20 to 16·32 volumes.

5th. That, for special reasons, the air is sometimes very impure. Thus, the crowded ward room pantry showed 19 volumes, the confined ill-ventilated store rooms which drew air second hand from the lower deck from 13·29 to 19·34 volumes, and the thrice vitiated air of the small worse ventilated cell or prison, derived from the store rooms, from 19·80 to 33·71 volumes.

6th. That officers and men breathe air nearly equally impure : ward room cabins averaging 14·49 volumes ; main deck ones 10·27 volumes ; the well-ventilated but crowded cadets' mess room 7·86 volumes ; their study 15·42, and, in rough weather, when barred in, 27·61 volumes ; their sleeping room below 16·62 volumes.*

* First wonder at the great impurity of ship air will cease, like my own, when the conditions are considered, especially the limited air space, lengthened crowding, and ventilation.

TABLE 2.—*To contrast the CO₂ in the air of different parts.*

		Number of analyses made.	Volume of CO ₂ per 1000 of air at different times of the night and day and different degrees of crowding.		
			Highest.	Lowest.	Averages.
Upper tier.	Main deck	10	16·3	7·83	11·04
	Half deck	1	13·99	13·99	13·99
	Study	3	27·61	5·59	15·42
	Mess room	2	11·53	4·20	7·86
	Main deck cabins	2	12·05	8·49	10·27
					11·71
Middle tier.	Lower deck	47	28·06	4·20	16·33
	Steerage	1	10·58	10·58	10·58
	Ward room	4	22·14	7·70	17·82
	Chest (cadets' sleeping) room	7	28·85	10·01	16·62
	Ward room and steerage cabins	2	16·23	12·76	14·49
	Do., pantry	1	19·34	19·34	19·34
					15·86
Lowest tier.	Stokehole	15	26·37	4·54	14·24
	Engine room	2	13·99	12·67	13·33
	Screw alley	2	11·21	9·34	10·22
	Cockpit	2	14·96	14·72	14·84
	Store room	3	19·34	13·29	16·42
	Cells	7	33·71	19·89	23·01
					15·34
Total		111	...	...	...
Highest		...	33·71	...	...
Lowest		...	...	4·20	...
Average		...	...	...	14·60

These figures show a great departure from the '4 volumes per 1000 (Roscoe) of the pure external air, alone fit for respiration,* and large excess over the '600 volumes in our best, the 1·98 volumes of our worst ventilated barracks (Parkes, Roscoe, Fyffe de Chaumont); and the '8 to 1 volumes in well ventilated private houses (Ertel). And they are more akin to the 3·1

* The quantity of CO₂ in pure sea air has not yet been determined. It is more difficult than might be supposed to charge a bottle with air completely out of the range of emanations from the ship. Analogy would lead us to suppose, however, that it is less than in land air.

volumes (Roscoe) in boys', and 7.23 volumes (Pettenkofer) in girls' schools, or the 3.65 volumes (Roscoe) and 10 volumes (Dalton) of crowded meetings. The smaller impurity in schools and assemblies than in ships arises from the crowding being neither so great nor prolonged, the air space greater, and the usually more perfect ventilation. In schools the lungs are smaller, but this and the carbon elimination are, perhaps, counterbalanced by the quicker respiration.*

So also according to the crowding and renewal of air the CO_2 may vary even on opposite sides of the same deck ; thus—

Main deck	Starboard (weather) side	...	...	9.26 volumes per 1000
	Port (lee) side (fewer sleepers and better ventilated)	...	...	7.83 „ „

For an obvious reason the CO_2 is also less near open ports, scuttles, hatchways, windsails, &c.

The CO_2 issuing from the lungs and skin of the men sleeping close to the beams overhead does not gravitate towards the deck, but is more or less rapidly diffused. Thus, on the lower deck at night (temp. 80°F.) the quantity in one experiment was identical in both places, viz. 7.8 volumes. On a second occasion, however (temp. 76°F.), it was densest near the deck by 0.71 volumes. The streams of pure air entering by many different channels, and the more numerous ones of impure air from the lungs, evidently do not mingle at once. This corresponds with the experiments of Lassaigue, Pettenkofer, Roscoe, and Gore. Moreover, the whitewash with which the interior of ships is often painted is usually found, after six weeks or two months, especially on the lower deck

* In connection with the impurity of ship air, it will be also useful to remember—

- 1st. That air containing more than 1 volume of carbonic acid per 1000 is unfit for *continued* respiration (Roscoe).
- 2nd. That expired air contains from 30 to 60 vols. (Taylor), and never more than 100 vols. (Allen and Pepys).
- 3rd. That air containing from 100 to 120 vols is speedily fatal to man (Taylor).
- 4th. That air containing from 120 to 150 vols. will extinguish a taper (Taylor).

between the beam, *i. e.* near the heads of the sleepers, to be highly effervescent under acids, and almost wholly converted into carbonate, proving that, altogether apart from its cleanliness and disinfecting properties (Angus Smith), frequent whitewashing with slacked lime is highly sanitary, because absorbent of CO_2 , and doubtless organic matter and watery vapour also.

The following table, regarding the lower or mess deck at sea, shows—

1st. That the CO_2 varies by night and by day, rising and falling with the crowding; and is great, *e. g.* at breakfast, 6½ a.m. (20·65 volumes), dinner, 12½ p.m. (25·74 volumes), and supper, 5½ p.m. (17·80 volumes), culminating at 7½ p.m. (26·53 volumes) when the men are mostly below and the lights lit.

2nd. That it remains high during night (14·98 to 19·54 volumes) when the ship is most shut in, and the ventilation often least attended to. Roscoe's experiments, showing that the lungs, especially of working men, absorb most oxygen by night, the blood storing it up for the following day, makes the great impurity of ship air during the long night watches, when the majority of the men are below and asleep, a fact of great hygienic importance.

TABLE 3.—*To contrast the CO_2 in lower deck air at different periods of the twenty-four hours.*

					Volumes of CO_2 per 1000 of air.
3 a.m.	...	...	...	...	14·98
6½ "	...	...	...	...	20·65
9½ "	...	...	...	...	14·24
10 "	...	...	...	...	13·24
Noon	...	...	...	...	13·45
12½ p.m.	...	...	...	...	13·87
12½ "	...	...	...	...	25·74
3 "	...	...	...	...	15·69
4½ "	...	...	...	...	9·38
5½ "	...	...	...	...	17·80
7 "	...	...	...	...	16·27
7½ "	...	...	...	...	20·65
7½ "	...	...	...	...	26·53
11½ "	...	...	...	...	19·54
11½ "	...	...	...	...	15·60

Table 4 shows that crowding has a like effect elsewhere, *e. g.* in the officers' quarters.

TABLE 4.—*To contrast the CO₂ in different parts when empty and crowded.*

				Volumes of CO ₂ per 1000 of air.
Ward room...	{ Empty	...	3 a.m.	7.10
	{ Full	...	7 p.m.	22.12
Gun room ...	{ Empty	...	3 a.m.	4.20
	{ Full	...	6½ p.m.	11.53
Cadet's study	{ Empty	...	3 a.m.	5.59
	{ Full	...	10 a.m.	27.61

The effect of the lower deck lights, *i. e.* *combustion* in increasing CO₂, as shown by table 3 (7½ p.m.), is still better illustrated by the boiler fires when steaming (Table 5), which made it rise in the stokehole from 12.87 volumes sailing, to 19½ under three, and 26.37 volumes under four boilers. It will presently appear that this added impurity is not local but generally diffused through the ship.

TABLE 5.—*To contrast the CO₂ in the stokehole under sail and steam.*

		Temp. of external air.	Volumes of CO ₂ per 1000.
Sailing in S.E. trade wind	...	81° F. (shade)	12.87
Steaming in equatorial doldrums with three and four boilers lit	...	82° F. (shade)	19.55 to 26.37

As CO₂ is constantly forming, thus requiring constant removal, it necessarily varies with the *ventilation*. Thus, Table 6, contrasting it when at anchor and unavoidably much closed in during rough wet weather, and when better ventilated at sea by trade winds, &c, shows—

1st. That it was everywhere reduced in the second instance from an average of 20 to 12.32 volumes.

2nd. That the reduction was greatest where most required,

i. e., on the lower or mess deck, viz. from 24.18 to 9.78 volumes.

TABLE 6.—*To contrast the CO₂ under different degrees of ventilation.*

	Indifferent ventilation; Simon's Bay.		Fair ventilation; S.E. trades near St. Helena.	
	Volumes of CO ₂ per 1000.		Volumes of CO ₂ per 1000.	
Main deck ...	12.09	...	9.72	
Lower deck ...	24.18	...	9.78	
Chest room ...	16.53	...	12.55	
Stokehole ...	16.64	...	9.76	
Bilge ...	20.22	...	11.83	
Store room ...	16.64	...	12.73	
Cells ...	33.71	...	19.89	
Averages ...	20.00	...	12.32	

The latter result was chiefly due to the rapid withdrawal of the foul air up the funnel by the agency of bogies in the boiler fires, in imitation of Baker's, Fanshawe's, and Edmonds' systems of outward suction by heat (nature's chief ventilating agent), largely employed in modern ventilation. This system, easy enough in sea-going naval ships, now invariably steamers, has been successfully applied* in H.M.S. "Britannia," a wooden three-decker, as it might in all similar harbour ships, by means of a large lit stove about the centre of the keelson, with a vertical funnel opening high above the upper deck.

The local and general purifying effect of small boiler fires, which create sufficient draught to carry off their own products along with the impure air, contrasts strongly with the vitiating effect of the larger ones employed for steaming (as shown by Table 5) which generate CO₂ and other noxious gases faster than they can be withdrawn by the funnel. On the other hand, for an obvious reason, the effect of open fires or bogies often wisely used to dry decks, &c., and sometimes erroneously to "burn up foul air," corre-

* In September, 1872. For description, see Reed's 'Naval Science' for April, 1873.

sponds to the latter rather than the former, inasmuch as they increase the impurity of ship air by adding CO_2 and even more noxious gases (SO_2 , CO , &c.), which are not directly carried off, but diffused. Thus, on one occasion while lower deck air showed 10·82 volumes of CO_2 , the usually pure engine room air, near two bright red bogies, had 12·67 volumes.

Any improvement or deterioration in the *ventilation*, resulting from the direction and strength of the wind, *i. e.*, the angle and force with which it strikes the ship, causes marked variations in the impurity of ship air. Thus, Table 7 shows—

1st (column 1).—That the CO_2 rose greatly throughout, *e. g.* on the lower deck to 18·59 volumes, in the sultry equatorial *calms*, from the external and the ship air being both almost stagnant.

2nd (column 2).—That when *steaming* in the same calms, it rose still higher, *e. g.* to 28 volumes on the lower deck, from the combustion of coal, and imperfect renewal of air.

3rd (column 3).—That it still remained high (*e. g.* 25 volumes on the lower deck) when riding or steaming *head to wind* during a breeze which glanced off the bows and sides, and that the foul air was driven aft, accumulating in the chest or cadets' sleeping room to 28 volumes.

4th (column 4).—That with the wind *abeam*, and fully entering her ports so as to blow the ship out, the CO_2 fell throughout, *e. g.* on the lower deck to 8·6 volumes, *i. e.* to one third of its former quantity.

5th (column 5).—That with the wind on the quarter or bow, *i. e. before or abaft the beam*, and, therefore, entering the ship imperfectly at an acute angle, the volume of CO_2 again rose, *e. g.* on the lower deck to 14·76 volumes.

TABLE 7.—To contrast the CO_2 at 11 p.m. when—1, sailing; 2, steaming; 3, riding head to wind; 4, sailing, wind abeam; 5, at anchor, wind on quarter.

	VOLUMES OF CO_2 PER 1000.				
	Column 1. Sailing in calms of equator. Temp. 81°F .	Column 2. Steaming in equatorial calms. Temp. 82°F .	Column 3. Barbadoes; riding head to wind. Temp. 80°F .	Column 4. Barbadoes to Bermuda; sail- ing side wind. Temp. 82°F .	Column 5. Bermuda; anchored, wind on quarter. Temp. 81°F .
Lower deck.....	18.59	28.06	25.03	8.60	14.76
Main deck	16.23	16.3	...	...	...
Stokehole	12.87	26.37	23.64	...	...
Chest room.....	20.69	...	28.25	10.01	...
Cells	23.15	...	25.96	21.8	...

As a rule, at least in fine weather, ship air is purer at sea than in harbour, because set sails materially aid ventilation, windsails, &c., act better, and the wind is usually stronger. But, as in harbour (Table 6, column 1) so at sea, a closed-in and badly ventilated ship, from rough weather, is followed by a great increase in the impurity of her atmosphere. Thus, near the Azores, from this cause, the CO_2 rose on the lower deck from 8.9 to 21.54 volumes.

Although ships, for coolness and comfort, are usually more opened out in the tropics, the preceding tables show that ship air, as a rule, is not purer there, because for several reasons it is more stagnant and less speedily diffused and renewed. There they generally sail *with* and nearly as fast as the wind, and there is less difference between the internal and external temperature to favour natural ventilation.

2. Sulphuretted hydrogen.

This, absent in pure air, is next to CO_2 , the most important gaseous impurity in ship air. Its usual sources are human and other animal excretions, and the decomposition of sulphates in salt-water leakage, by rotten timber. Tested

at night by blotting paper charged with Acet. Plumbi, the following table shows :

1st. That SH_2 pervades and to a certain extent surrounds a ship.

2nd. That it is most abundant below, especially on the middle and lower decks, where the men are berthed.

3rd. That the reaction was most decided in the lowest tier, especially the bilge; doubtless not so much from the presence of the SH_2 as of sulphide of ammonium, the chief cause of the familiar bilge smell of wooden ships.*

TABLE 8.—*To contrast the relative abundance of SH_2 in different parts of a ship; temp. 82°F . near Barbadoes; exposure 12 hours (11 p.m. to 11 a.m.); ventilation fair; north-east trade wind.*

	UPPER TIER.						MIDDLE TIER.				LOWEST TIER.				
	Upper deck.	Half deck.	Main deck.	Main deck cabins.	Cadets' study.	Cadets' mess room.	Chest room.	Ward room.	Steerage.	Lower deck.	Engine room.	Stokehole.	Store room.	Cells.	Screw alley.
A trace	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...
Decided trace	...	...	1	1	1	1	1	1	1	1	1	...	...	...	...
Very decided trace	...	...	...	...	...	...	...	...	...	...	...	1	1	1	...
Strong trace	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
Very strong trace	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1

The following results of 25 experiments† at different periods of the night and day show (Table 9) :

* The musty odour which sometimes emanates from the lining of wooden ships doubtless often arises from mould or minute fungi.

† Determined by absorption by water. To a $1\frac{1}{2}$ gallon glass jar filled with the air to be examined, 8 oz. of distilled water was added, the jar then corked

1st. That the actual quantity of free SH_2 varied from $\cdot 000578$ to $\cdot 049049$ volumes per 1000.

2nd. That it increased with the crowding and the impurity of the bilge.

3rd. That the quantity was greatest when CO_2 was abundant (*e. g.* $16\cdot 09$ vols. on the lower deck), and the air generally most impure.

TABLE 9.—*Sulphuretted hydrogen.*

				Volumes of SH_2 per 1000.
Lower deck	...	...	...	$\cdot 000578$ to $\cdot 049049$
Ward room cabins	...	...	...	$\cdot 014714$
Bilge	...	...	...	$\cdot 0490494$
Cell (one occupant)	...	...	...	$\cdot 000425$

3. *Ammonia.*

The usual sources of this are—human urine, the excreta of fowls, combustion of coal, animal and vegetable decomposition in the bilge, &c. The brownish discoloration of log-wood paper showed (Table 10) :

1st. That this highly diffusible gas, or its compounds, is always and everywhere present in ship air.

2nd. That it is most abundant when and where there is most crowding, *e. g.* in the sleeping berths, mess rooms, studies, and occupied cells.

3rd. That it was less abundant in the clean bilge and hold tier generally.

tightly, frequently shaken for 12 hours, and then tested by Sol. Iodid. Potas. and starch, according to the formula given in Parkes's 'Practical Hygiene.' It is much to be regretted that we have no such delicate test for SH_2 as Nessler's beautiful one for ammonia.

TABLE 10.—*Ammonia ; relative abundance.*

	UPPER TIER.						MIDDLE TIER.				LOWEST TIER.						
	Upper deck.	Half deck.	Cadets' study	Cadets' mess	Main deck	Main deck	Chest room.	Ward room.	Steerage.	Lower deck.	Store room.	Cells.	Engine room	Screw alley.	Stokehole.	Cockpit.	Bilge.
A trace	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1
Decided trace	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Very decided trace ...	...	...	1	1	1	1	1	1	1	1	1	...	1	1	1	...	...
Strong trace	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...

The following results of 15 experiments by Nessler's test,* at different periods of the twenty-four hours, shows (Table 11):

1st. That its quantity varies from '0008 to 3·029 average '31857 grammes per 1000 cubic feet of air, a considerable excess over the trace found in pure air, too small, according to Fownes, for direct estimation.†

2nd. That the highest amount was found on the lower deck at 10 p.m., shortly after the crew had turned in during rough weather and a closed-in ship, when the CO₂ was 21·54 volumes.

3rd. That it was also high on the lower deck during dinner, viz. 0°1699 grammes.

4th. That it is high in confined, badly ventilated cabins.

5th. That in the bilge it rose to 1·088 grammes when this had not been sluiced for some days.

* Determined by absorption by water. To a 1½ gallon glass jar filled with the air to be examined, 8 oz. of distilled water was added, slightly acidulated by Acid. Sulph. Dil., as recommended by H. T. Brown ('Proc. Roy. Soc.,' vol. xviii, p. 287, foot-note). The jar was then corked tightly, frequently shaken for 12 hours, and tested by Nessler's solution in the usual way.

† Roscoe gives the quantity as 1 volume in 1,000,000. According to H. T. Brown ('Proc. Roy. Soc.,' vol. xviii, p. 287) the extreme results on record vary as much as from '135 to '0001 parts for 1000 of air.

5.—*Oxydisable organic matter.*

A minute quantity (1 grain in 200,000) of organic matter is found even in the purest mountain air (Watts), also in pure country air, and necessarily more abundantly in town air, its source, in all, being animal and vegetable emanations. It doubtless exists in pure sea air though to a less extent.

The chief sources of this important impurity in ship air are, exhalations from the crew, cargo, and ship, especially the first. Hence, it is most abundant below, and when and where there is most crowding. Hence, also its amount in many cases closely corresponds to, and rises and falls with, the CO_2 . Thus, Table 13 shows :

1st. That it takes only from 5 to 12 cubic feet of the air examined to decolorise 1 milligramme of potas. permanganate.*

2nd. That it is abundant in lower-deck air at night.

3rd. That it is very abundant in the confined cells when occupied, and the CO_2 therefore high.

In warm and especially tropical weather the organic matter is greater and more evident to smell, because of the increased exhalations from the crew and the more stagnant and septic state of the air. It is the volatile organic matter, especially that thrown off by the skin, which gives ship air where there is most crowding and least ventilation, as in the cells and lower deck at night, its close and often nauseous smell. Hence why, though perhaps as highly laden with CO_2 , the air of officers' cabins, mess rooms, and sleeping berths, has a less sickly odour than that of a lower deck, which possesses few or seldom used baths and lavatories, so essential to cleanliness and health. Nevertheless, as pointed out by Parkes, the quantities of organic matter and CO_2

* The quantity of oxydisable organic matter was determined by slowly passing the air through the permanganate solution by the aspirator described in the 'Lancet,' Dec. 28, 1872. Parkes states that as the quantitative relations of the organic matter of air and potassium permanganate are not yet accurately known, the result should be simply noted, as done in Table 13.

usually bear a certain relation, especially among persons of corresponding cleanliness or carelessness, and increase or decrease together, because the sources of the two impurities are the same, viz. the skin, lungs, and mucous membrane.

TABLE 13.—*To show the quantity of oxydisable organic matter in various parts, and its relation to the CO₂.**

		Carbonic acid in 1000 volumes of air.		Air required to decolorise '0001 grammes (= milligramme) of potas. permang.
Cells, 6 p.m.	...	31·823	...	5 cubic feet.
Lower deck, 10 p.m.	...	8·991	...	10 „
Do., 3 a.m.	...	14·76	...	12 „

6. Watery vapour.

Watery vapour is usually more abundant in ship than in ordinary air, its chief sources being exhalations from the lungs, skin, ship, &c. In 130 observations in tropical and temperate latitudes it varied from 4·5 to 12 grains per cubic foot, *i. e.* relative humidity 69 to 95, average 79 per cent. ; a considerable excess over the 65 to 75 per cent. best fitted for health (Parkes) in temperate latitudes. Table 14, for 3 a.m. the crew berthed (as in Table 1), and the ship housed for the night at Ascension, temp. 78° F. (external air) shows :†

1st. That it is most abundant, exceeding that of the open air, on the crowded lower and main decks, also in the confined ill-ventilated store rooms with seven sleepers, and, worst of all, in the adjacent “cells.”

2nd. That elsewhere it diminishes *pari passu* with the crowding, and was least where empty.

* It should be remembered, however, that the unavoidable presence of sulphuretted hydrogen and sulphide of ammonium in small quantities in ship air, is apt to interfere with the accuracy of the results given in this table. It is to be regretted that we have not a more accurate chemical test for organic matter than the permanganate.

† These and the following results were obtained by the ordinary wet and dry bulb-thermometer and Glaisher's tables.

3rd. That it is also lessened by good ventilation and fires, as in the stokehole, the lower deck near the funnel casing, and main deck near the galley, where the humidity was less than in the external air and nearest the healthy standard.

TABLE 14.—*To contrast the humidity in different parts of a ship.*

Place.	Watery vapour.	
	Grains per cubic foot.	Relative humidity.
External air	6·74	79
Upper tier {	Main deck	9·39
	" opposite galley.....	6·87
	Half deck	6·57
	Study	6·74
Middle tier {	Lower deck	10·10
	" opposite funnel ventilator.....	6·96
	Ward room.....	7·23
Lowest tier {	Cockpit	7·19
	Engine room	7·00
	Stokehole	5·70
	Bilge	6·24
	Store room (7 occupants)	9·69
	Cells (1 occupant)	10·43

Table 15 shows that the humidity of ship air during the twenty-four hours rises and falls with the crowding, and is greatest at dinner when "all hands" are below (9·6 grains = rel. humid. 80).

TABLE 15.—*Humidity of ship air as affected by crowding ;
lat. 7° S. ; Atlantic ; temp. 79° F., external air.*

Place and conditions.				Watery vapour. Grains per cubic foot.	Relative humidity. Saturation = 100.
August 21st	9½ a.m.,	lower deck,	empty	8·603	76
	Noon	"	full	9·624	80
	5½ p.m.	"	empty	8·150	72
	7½ "	"	full	9·356	80
	11½ "	"	two thirds full	9·056	80

The following corroborates Table 14, and shows that defective ventilation increases the humidity of ship air (Table 16).

TABLE 16.—*Humidity of ship air as affected by ventilation.*

Conditions.				Watery vapour. Grains per cubic foot.	Relative humidity. Saturation = 100.
Lower deck	11 p.m.	{ Barbadoes, riding head to wind		10·22	85
		{ At sea, with better ventilation.		8·95	68
	3 a.m.	{ Bermuda, wind nearly aft		10·18	90
		{ At sea, with better ventilation.		7·93	77

The humidity is also increased by washing decks, clothes, bathing, &c. ; thus—

TABLE 17.—*Humidity of ship air as affected by washing decks, &c.*

Conditions.	Lower deck.		Open air.	
	Grains per cubic foot.	Relative humidity.	Grains per cubic foot.	Relative humidity.
Washing lower and main decks, temp. $\left\{ \begin{array}{l} \text{Lower deck, } 82^{\circ} \text{ F } \dots\dots \\ \text{Open air, } 80^{\circ} \text{ F } \dots\dots \end{array} \right\}$	9.569	85	8.784	80

The humidity is necessarily greatest under a combination of these causes, *e. g.* when the crew are below and perspiring, as when washing decks, at sea and the ship much shut in, especially in the warm and humid tropics.

On the other hand, steaming diminishes the humidity of ship air by heating it and the ship throughout; thus, Table 18 shows that when the external and relative humidity was 80 it was only 68 on the lower deck, *i. e.* nearer the boiler fires.

TABLE 18.—*Humidity of ship air as affected by steaming.*

	Watery vapour. Grains per cubic foot.	Relative humidity. Saturation = 100.
Steaming in equatorial doldrums, $\left\{ \begin{array}{l} \text{Air, external, temp. } 82^{\circ} \text{ F. } \dots\dots\dots \\ \text{,, main deck ,, } 82^{\circ} \text{ F. } \dots\dots\dots \\ \text{11 p.m. } \dots\dots\dots \left\{ \begin{array}{l} \text{,, lower ,, } 86^{\circ} \text{ F. } \dots\dots\dots \end{array} \right. \end{array} \right.$	9.36 8.86 8.95	80 76 68

In the stokehole, where the temperature was 107° F. , the humidity was doubtless much less. But as Glaisher's tables do not range so high, the exact quantity cannot be calculated.

Ship air is more humid at sea than in harbour, like the

external air. Like this also, the humidity of ship air is greater in tropical than in temperate regions; thus—

TABLE 19.—*Humidity of ship air in temperate and tropical climates.*

Place and conditions.	Watery vapour.	
	Grains per cubic foot of air.	Relative humidity. Saturation = 100.
Lower deck, crew at dinner	Cape of Good Hope, lat. 33° S., temp.	
	59—69° F.	5½—6½
	Equatorial doldrums, lat. 5° N., temp.	73—74
	84—87° F.	10—12
		82—87

7. *Suspended matters.*

The fine dust in ship air consists chiefly of *débris* of wood, metal, sails, rope, &c., from the ship, and particles from the bodies, clothing, food, &c., of the crew. Three grains of fine greyish dust from between the beams of the lower deck burnt and smelt like tinder, leaving 0·8 grain of a brownish-black indestructible ash, thus consisting of—

Inorganic matter	26·66 per cent.
Organic „	73·34 „

while the microscope showed fibres of cotton, linen, wool, epithelium and gritty matter (Plate III, fig. 1). In the air of the lower and main decks passed through an aspirator were seen minute living acari (fig. 2, *A. Farinæ* ?), legs, &c., of insects (fig. 3), small, round, and oval bodies, diameter $\frac{1}{1000}$ inch (figs. 1 and 3), probably identical with those observed by Lemaire in the air of a prison and the sweat of a dirty person, and also by Trautman in air, especially when impure (Parkes). As with ordinary air, important etiological results would doubtless follow a systematic microscopic examination

of ship air, especially during the presence of contagious diseases (Class A).

8. *Temperature.*

As regards the temperature of ship air the following table (20) shows—

1st. That, like the external air, ship air generally is cooler by night than by day, the difference being greatest in summer.

2nd. That in winter, owing to fires, crowding, and a closed-in ship, the interior is considerably warmer than the open air, *e. g.* from 7° to 12° F. or more by day, and from 13° to 20° F. or more by night. Again, in summer, while the internal and external temperatures are more equal, the external is warmer by day from solar heat, while by night the internal is from 7° to 10° F. warmer from crowding and closing in.

3rd. That, as a rule, and for an obvious reason, ship air is 1° or 2° F. cooler near the mouth of hatchways, ports, scuttles, windsails, ventilators, &c., opening externally, and correspondingly warmer near those opening from below.

4th. That ship air, both by night and day, is warmest near fires, and especially when the ship is most shut in and where the crew is most crowded.

5th. That it is warmer on the lee than the weather side of the ship.

6th. That it is warmer close to the beams and sleeping crew than near the deck.

7th. That, notwithstanding crowding, closing in, fires, &c., the temperature of a ship's interior may, especially by night and in winter, be cooler than consistent with comfort and perhaps health.

8th. That the above laws hold good for the tropics, although, because of fewer fires and lights, there is less difference between the external and internal temperatures. Again, by day the greater stagnation and humidity of ship air, and slower cutaneous evaporation, make it, though actually lower in temperature, *apparently* warmer than the external air,

while by night the same causes *apparently* increase its greater heat.

TABLE 20.—*Actual and relative temperatures of ship air.*

Place.	Temperate zone. H.M.S. "Britannia."				Tropics. H.M.S. Bristol.
	Summer, May 27th, 1872.		Winter, October 24th, 1873.		October 6th, 1871.
	Day, 1 p.m.	Night, 10 p.m.	Day, 11½ a.m.	Night, 11½ p.m.	Night, 10 p.m.
External air (shade)	68	51½	38½	30 and under	77
Main deck.—Studies	63½	61½	48	49	...
Weather side	66	60	47½	49½	78½
Lee side	...	...	...	...	79½
Near fore hatch, lead- ing below	...	...	...	...	80
Near a starboard port	...	...	...	...	78
Middle deck	65	56	46	50	...
Lower deck.—Weather side	64	55½	51	43½	81
Lee side	...	...	...	...	82½
Near beams	...	...	...	...	82½
Near deck	...	...	...	...	82
Near mouth of a windsail	...	...	...	...	78½
Near fore hatch, leading on deck	...	...	...	...	80½
Near main hatch, leading on deck	...	...	...	...	79½
Near funnel, casing ventilator	...	...	...	...	80
Officers' cabin, wea- ther side	...	...	...	...	79½
Officers' cabin, lee side	...	...	...	...	80
Cockpit	62½	54½	48	47½	80½
Model room (after cockpit)	61½	54	47	46	...
Engine room	...	...	...	...	79½
Hold	59½	...	45½	45	...
Stokehole	...	...	...	...	79
Bilge	...	...	...	...	79
Highest	66	61½	51	50	82½
Lowest	59½	54	45½	43½	78
Range	6½	7½	5½	6½	4½

The following analysis of bilge water, which so often contaminates ship air, will be interesting. One litre, collected seven days after the bilge had been sluiced, was of sp. gr. 1031 and temp. 74° F. (sea water being sp. gr. 1027 and 71° F.). Supernatant fluid tolerably clear, strongly alkaline, smell fetid, test paper charged with Acet. Plumbi becoming dark by five minutes' close exposure to its surface.* Sediment copious, dark, of a highly offensive odour, and showing under the microscope small particles of wood, sand, coal, whitewash, &c., its weight being—

4.082 grammes	{	2.527 grammes inorganic matter, effervescent and partly
		soluble in acid. sulphuric. dil.
		1.555 grammes organic matter, destructible by heat.

The basis of bilge water is sea water, with certain added soluble and insoluble foreign matters. Of the soluble, 1 litre contained—

1. Sulphuretted hydrogen (test, Sol. Iodin. and starch) = 0.059925 gramme or 2.54 cubic inches = 0.0564 gramme of sulphur.

2. Ammonia (test, Nessler's) = 0.1269 gramme, probably chiefly sulphide.

3. Sulphides (test, Sol. Acet. Plumbi in soda) abundant, especially sulphide of ammonium, but the quantity was not determined.

4. Lime in solution (test, Oxal. Ammon.), 2.268 grammes of oxalate of lime = 0.697 gramme of lime (Ca 2HO).

5. Carbonic acid (test, Aq. Calcis), a slight deposit.

6. Organic matter; 1 litre decomposed 0.141 gramme of permanganate of potas. almost instantaneously. However, free SH_2 and sulphide of ammonium necessarily render this test and result to some extent doubtful.

* This was a comparatively mild specimen of bilge water.

9: Medical bearings of the case.

The chemical interest attached to the present inquiry is surpassed by its medical importance, inasmuch as it leads to the threshold of another still more abstruse, viz. the sole or joint effect of impure ship air on the physique of seamen, and on the origin, character, and course of the various diseases prevalent among them. As a rule, our most successful preventive and curative efforts are those based on exact physiological and pathological knowledge. Of the subject here indicated, however, only the leading features can be now discussed, with a few illustrative examples selected from a doubtless fertile field of research.

Seamen, as a body, are neither healthy nor long lived, but the reverse. This is proved, first, by their low average age, said to be 33, evidently too brief for men who are carefully selected, and subsequently kept under the most approved hygienic influences; and, second, by their sick and death rates equalling those of landsmen, who include the two periods which contribute most to both lists, viz. infancy and old age. This indicates subjection to certain unhealthy agencies, of which impure air is evidently one, and perhaps the most powerful. So great is the vitiation that we cannot but wonder that seamen keep their health, such as it is, so well, and can only explain it by their longer subjection on deck to the purest of all air, which, to a certain extent, counteracts the evil effects of the impure air breathed below, and prevents the system from sooner succumbing to its influence. Although ship air may be, and often is, long breathed with apparent immunity, it is really slowly but surely undermining the constitution, partly by poisoning the blood and tissues, and partly by depriving them of oxygen. To its prolonged effect is doubtless partly due the pale sickly hue of men kept much below, and mainly the stunted growth of seamen generally, their premature old age, comparatively early death, and much of the disease which prevails among them.

The more immediate influence of the constant or frequent inhalation of this impure air in the production of disease is effected in two ways, either locally and mechanically, or generally and chemically, thereby inducing many slight and serious, obscure and obvious results. The blood, laden with retained and perhaps reabsorbed carbonic acid, lingers in the lungs, craving to be oxygenated, thus gorging them. Nightly or oftener renewed, this passive congestion becomes progressively greater and more permanent, and the lungs thereby increasingly prone to inflammation. What more likely to excite the latter than the chill resulting from the sudden transition from a warm hammock into the cold external air, and the consequent inward revulsion of blood, especially into the breathing organs, to which the majority of every crew is subjected once, and often twice, every night when roused to keep watch. If then sent "aloft," and both lung and heart function thereby greatly and suddenly increased, the lung circulation is likely to become still further impeded, and, as a sequel, the heart and great vessels secondarily distended, embarrassed, and laboured in action. What is the effect of a frequent repetition of this on the pulmonary and cardiac systems? How many of the 6796 cases of catarrh and other inflammatory lung diseases, and of the 392 cases of morbus cordis, which occur annually among the 50,347 originally strong, healthy, selected men in H. M.'s Navy, are to be thus directly or indirectly accounted for?*

Without attempting to specially consider the individual effects of organic matter, sulphuretted hydrogen, and other impurities, beyond noticing their undoubted and even, according to some, paramount unhealthy influence,† it will be

* These averages are for three years (1867-8-9) taken at random.

† The most important class of diseases produced by impure air is certainly caused by organic matters, especially floating ones (Parkes). The respiration of an atmosphere only slightly impregnated with sulphuretted hydrogen may, if long continued, seriously affect an individual, and even cause death (Taylor). Ammonium sulphide is still more poisonous; but authorities are much divided regarding the quantities which injuriously affect health, doubtless because their influence, like that of other poisons, varies according to

obvious that as the blood gets laden with these, and especially carbonic acid, the function of the red corpuscles as oxygen carriers, and that of the white globules as fibrin elaborators, becomes impaired, and the liquor sanguinis thus soon chemically and vitally altered. Instead of oxygen it carries poison, and hence, instead of healthily stimulating, it narcotises the nervous, muscular, glandular, and other tissues and systems, producing certain effects, immediate and remote. Hence, for example, the lethargy, headaches, nausea, malaise, and other minor ailments common on ship-board, especially among the newly called night-watch, and officers in crowded studies, cabins, and mess rooms, especially in the tropics. Moreover, impure blood yields faulty gastric, hepatic, and other secretions, and thus vitiates digestion and primary assimilation. While by the resulting limited production of albumen, aided by the impaired function of the white blood-corpuscles and the deficient supply of oxygen in ship air, secondary assimilation and nutrition, including growth and the ordinary renewal of tissue, become defective.

The doubly imperfect nutrition resulting from vitiated air and faulty dieting is exactly the condition in which struma is most likely to be acquired, or developed in an hereditarily predisposed subject; hence, doubtless, the 384 cases of scrofula which occur annually in H. M.'s Navy; and the above-noted mechanical obstruction explains why, in seven eighths of these, its semiorganised deposit is determined to the gorged lungs, to manifest itself in the imperfectly nourished lung-tissue in the form of phthisis. Baudelocque's belief that vitiated air is the real source of the strumous diathesis, and that other agencies usually accredited with the production of phthisis, *e. g.* deficient exercise, want of cleanliness, exposure, &c., though important aids, are only secondary and subordinate causes, of themselves non-effective, is doubtless correct, as are the

individual susceptibility, and the state of health at the time of subjection to them. One thing, however, is certain, they are all abnormal and unhealthy, and doubtless add to the general result.

opinions of the Army Sanitary Commissioners, Bryson, Milroy, and others, who ascribe the great prevalence of phthisis in the army and navy chiefly to impure barrack and ship air. Blood vitiated and tissues impoverished to this extent fall an easy prey to disease on the addition of a fresh blood poison, whatever its nature; and this explains why the semi-scorbutic, rheumatic, and other blood diseases are predisposed to, and more prevalent among seamen than they might be.

Whatever the true nature of contagious diseases, especially the exanthemata, impure ship air unquestionably aids their propagation, both by affording their germs a suitable medium in which to become developed, and predisposing the blood and system to receive and multiply them. Erysipelas (which led to the present inquiry), first developed in the heat and humidity of the Equator, continued to occur in H.M.S. Bristol, in accordance with a law already well known, whenever she was more shut in and less ventilated than usual, and her atmosphere thus unusually vitiated, as at Simon's Bay, Barbadoes, the Equator, Bermuda, and near the Azores (see tables), where the CO_2 varied from fourteen to twenty-four volumes per 1000, organic matter and other impurities being correspondingly increased. Fig. 4—blood from an erysipelatous leg, in which a minute active animal was found about one third the diameter of a red blood-corpuscle* (diameter $\frac{1}{12000}$ inch), is given more as suggestive of continued examination of the blood in contagious diseases than as offering any explanation of the nature of erysipelas. However, whether these organisms were the cause or merely the result of this disease, I have more recently (1872) seen a similar equally active animalcule in the blood of an erysipelatous scalp.

The high impurity of modern ship air suggests how much greater must have been the vitiation of former times in smaller, more crowded, and less carefully ventilated vessels. Nor are their high sick and death rates surprising, or the great

* Seen also by my colleague, Surgeon Charles Fennel, R.N.

prevalence of scurvy, putrid fever, sloughing ulcer, dysentery, and other diseases arising from blood poisoning. The same cause is still at work among seamen, though in a minor form, producing similar widespread, though necessarily less marked, pathological effects. All medical authorities agree regarding the highly injurious effects of the various impurities found in ship air; and remembering that pure air is one and the most urgent of the indispensables of health, and hence that an atmosphere, at once so vitiated and so constantly undergoing recontamination as ship air, cannot be too often renewed, the facts here adduced suggest various sufficiently obvious hygienic indications, not only regarding ships of war, but vessels of every nation, kind, and class. We cannot on shipboard, as on shore, except to a trivial extent, reduce the vitiation by increasing the cubic air space, and are thus compelled to adopt the only other available plan, viz. more frequently renewing the air, *i. e.* increasing the ventilation; and, regarding this, it must be obvious—1st, and more especially, that from the beginning to the end of a ship's active career her ventilation should not be deemed of secondary but of primary importance; 2nd, that ships should have the best possible ventilating apparatus; 3rd, that this should be always efficient, ever at work, and constantly looked after, even if "automatic" or "self-acting;" 4th, that increased attention to ventilation is necessary at certain periods, especially at night, during meals, and peculiar conditions as to crowding, direction of wind, &c.; and 5th, that, so necessary is a constant and complete renewal of air to attain the greatest possible purity, we should not trust solely to any single system, but in turn or conjointly employ propulsion, suction, and diffusion, aided, whenever possible, by other means, as scattering the men towards the best ventilated parts, &c. The more we perfect ship ventilation and the purer we make the atmosphere in which seamen live, the healthier will navies become. There is no apparent reason why ship air should not be as pure, if not purer, than barrack or house air. To make seamen thoroughly healthy the unsanitary agencies to which they are subjected must be

altogether, or at least in great measure, removed ; and if we succeed in removing this, doubtless the most powerful of them all, they will as a class become healthier and longer lived than landmen, and even than soldiers.

DESCRIPTION OF PLATE III.

FIG. 1.—Fine dust from lower deck. (Magnified 30 diameters.)

FIG. 2.—Living acari from lower deck, night air. (Magnified 30 diameters.)

FIG. 3.—Small round and oval bodies in lower deck, night air. (Magnified 30 diameters.)

FIG. 4.—Blood from an erysipelalous leg containing animalcules (*a*, magnified 250 diameters); ditto (*b*, magnified 500 diameters).

Fig 1.
Mag 30 diam.

Fig 2.
Mag 30 diam.

Fig 3.
Mag. 30 diam.

Fig 4.
Mag. 250 diam.

500 diam.
b