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John Scott Russell Esq. F.R.S.,
&c., &c.

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Ebening Meeting.

Monday, May 19, 1879.

ADMIRAL SIR COOPER KEY, K.C.B., Member of Council,
in the Chair.

ON STORM STABILITY AS DISTINGUISHED FROM SMOOTH-WATER STIFFNESS.

By JOHN SCOTT RUSSELL, Esq., F.R.S., &c., &c.

I AM deeply sensible of the high honour you have done me in selecting me to prepare for you a statement and explanation, and practical applications of a portion of hydrodynamical science, of nautical experience, and of naval construction, which has not hitherto been truly completely, or usefully treated either by philosophers or practical men.

The title you have given me for the paper has been most wisely chosen. It shows that experienced sailors know much better than landsmen what it is that constitutes a good sea-going, sea-keeping ship. It tells us that what the sailor wants for his ocean-loving home is not the fine-weather yacht, nor the smooth-water floating fortress built by modern landsmen, but the sea-going, sea-loving, ship-shape ocean man-of-war, which is always stable, quiet, gentle, easy, and graceful, whether in smooth ocean swell, or in the storm of the hurricane, or on the breakers of the tempest.

Now I am quite willing and ready to fulfil the arduous duty you have given me. I have devoted all my recent leisure to getting at the bottom of all the unsolved questions which it involves; but I am obliged to confess at once that I cannot fulfil the whole of the task set me, in one sitting, in a manner worthy of the subject or worthy of the audience. I have, therefore, at once to beg you will excuse me if at the end of our meeting you find that I have not exhausted this prolific and useful subject, but only opened it up and covered a small part of a very wide investigation.

In this difficult position I think I can be most useful if I first give you an inventory of the subjects to be considered, and of the elements of the questions to be asked and solved, and afterwards I may take up some of these questions and leave the rest till another time.

Inventory.

1. What is a storm ?
2. What is smooth water ?
3. What is stiffness ?
4. What is stability ?
5. How is a storm created from smooth water ?
6. How is smooth water got out of a storm ?
7. How is a stable ship made ?
8. How is a stiff ship made.

The answers to these questions open up quite another series of questions which inevitably follow :—

9. What is the nature of sea waves ?
10. What is the nature of breakers ?
11. What is the nature of a ground swell ?
12. What are storm waves ?

Afterwards follow these questions :—

13. How is a crank ship to be made stable ?
14. How is a stiff uneasy ship to be made easy and stable ?
15. How is a ship to be made stable in storm ?
16. " " easy in tempest ?
17. " " gentle on swell ?
18. " " stiff under canvas ?
19. " " steady on waves ?

And at the same time—

20. Crankness,	} to be avoided.
21. Rolling,	
22. Capsizing,	

PART I.

Now I will start at once with the fulfilment of my duty by taking up each of these questions.

I think that for your purpose it will be most convenient that I should begin at the end. I therefore at once take two forms of ship, both equally bad and of opposite badness, and ask you to choose the better from the worse as our first step in progress. (See Figs. 1, 2, 3.)

FIG. 2.

FIG. 1.

FIG. 3.

The Rock.

The Raft.

The Ship.

The ship-shape is easy, lively, stable, and gentle.

The raft is lively and stable in smooth water and fine weather only.

The rock is steady and stable in all weather, never easy, gentle, nor lively, always quarrelling with the waves until beaten in or broken up.

Let us now study the behaviour of each of these ships on the waves, and the causes of that behaviour.

1. The shoulders of the raft are too broad and too strong. They are so powerful and so large, that smooth-water waves and small seas have not size nor power to move them fast or far, and therefore move them slow and gently.

But these broad shoulders are just the levers which the storm waves use to jerk the raft up and down with quick, violent motion, and they furnish the powerful lever by which the destroying waves called wreckers or breakers get hold of the ship, mount upon the deck, and overwhelm it.

Thus the shoulders which give smooth-water stability, give violent motions and dangerous positions under the attacks of storm waves.

2. The rock, on the contrary, is stiff and upright in smooth water, and carries great press of sail with small inclination. But it stands too upright and too stable when among the storm waves, for the wave-motions are both horizontal as well as vertical, and the violent horizontal motions of storm waves in the cross sea, first deal violent blows on one side and then on the other, to which this rock does not yield, and this violent collision first strains the ship, next takes the sea on and over her, and at last injures her structure, and may break her up in the end, and send her down.

3. Is there a middle form between these two which possesses the good qualities of *both* without the faults of *either*?

To discover this form is the problem you have set me. This problem I have undertaken, but I do so with a deep sense of its difficulty, both as to the perfectly precise, true, and exact solution of the problem, and especially as to my ability to make so deep and complex a question a matter of verbal explanation. But I have one comfort, I am glad it is *you*, the practical and experienced men of the sea, who have asked me for this explanation; that tells me that you feel it to be a great want, and your asking me makes the solution of it a great duty, which I now feel bound to fulfil as best I may.

The problem has two parts:—

The nature of the stormy sea.

The nature of the seaworthy ship.

Whence the two questions—

I. How is the water behaving on the ocean when gentle winds make gentle waves, and how, otherwise, in storms and amid breaking waves?

II. How should a ship be built so as to behave well and keep gentle and quiet equally amid ocean waves in fine weather and ocean waves in tempest, tumult, and storm?

I. The behaviour of water in wind and storm is generally expressed by the words—waves, swell, and breakers.

We may, therefore, first take smooth water, and ask how it becomes troubled and stormy? To discover the answer to this question I had to devote ten years of continuous observation to the study of waves and water-motion, and to exact experiment and observation upon them. I will endeavour to give you the results in few words.

I found there were four kinds of water waves, all quite different in nature. The skin wave, the surface wave, the ground swell, the unseen wave.

1. *The Skin Wave*.—If you look at a smooth sea on a still day, you will see here and there gentle wrinkles on the face of the water; they may be long though small and narrow—mostly quarter of an inch to two inches broad—like threads or ribbons skimming along the smooth, shining, mirror-faced water. These are caused by gentle airs in still water, and also by under-water currents in disturbed water. You can make them by moving a slender thread or line along the water, as in fly-fishing, or by cutting the skin with a penknife as you row gently along smooth water.

I found that these beautiful little waves were the consequence of a strange fact then unknown. The surface of the water where it meets the air is parted off from above and from below by a solid, strong, tough skin, quite unlike the water below: it is hard, unyielding, and solid, like ice. If ice were tough and would bend easily, I should call this skin "ice;" but ice cracks when you bend it. This is so tough that it bends easily; you can cut it with a knife, but it requires a pressure of about half an ounce to an inch to cut or split it, or $4\frac{1}{2}$ lbs. to the foot is the limit of its toughness; it is like leather rather than ice. In bright sunshine in a clear stream you can see it play all sorts of tricks, and you can see the wind and the fish and flies playing all sorts of tricks with it. The skin waves cover the surface with wrinkles on the first approach of the wind.

2. *The Surface Waves*.—The first symptom of coming wind in smooth still water is a series of long lines of skin waves, each not more than 2 inches broad. As the wind advances it soon makes itself felt by heaping up the wrinkles of the skin waves into piles and rows and ridges, growing from 3 and 4 inches wide and $\frac{1}{2}$ an inch high, gradually on to 3 and 4 feet wide and $\frac{1}{2}$ a foot high.

The standard wave, by which I measure and compare the times and speeds of all other surface water waves, is as established by my original observations, 1834—1844.

FIG. 4.
Standard Surface Wave.

One second time. Speed 3.57 feet".
Limiting height one foot.

The Standard Wave. $\left\{ \begin{array}{l} 3.57 \text{ feet long, from crest to crest.} \\ 3.57 \text{ feet per second, speed of travel.} \\ 1 \text{ second of time—duration.} \end{array} \right.$

The model wave, by which I measure the form and calculate the phases

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and heights and rise and fall of waves is as shown in the large Diagram. (Plate XXXV.)

The Model Wave. $\left\{ \begin{array}{l} 8.33 \text{ feet high.} \\ 57.12 \text{ feet long.} \\ 14.28 \text{ feet a second speed of travel.} \\ 4 \text{ seconds of time—duration.} \end{array} \right.$

All other waves of this order may be thus calculated by the standard.

TABLE I.

Table of Surface-Sea Waves. Calculated by the Standard.

Time.	Lengths.	Speeds.
	Fect.	Fect.
1	1. Standard = 3.57	3.57
2	4. Standards = 14.28	7.14
3	9. " 31.63	10.71
4	16. " 57.12	14.28
5	25. " 89.25	17.85
6	36. " 123.52	21.42
7	49. " 176.03	24.99
8	64. " 228.48	28.56
9	81. " 280.17	32.13
10	100. " 357.67	35.70

Heights of surface waves are *not* inserted in the table for important reasons.

The chief reason is isochronism. It may seem strange, but it is exactly true, that a wave of given length and given time may vary in height from highest to lowest, and yet never take longer or shorter time to go through its changes of form or changes of place.

But there is an extreme or limiting height to each wave. This may be called the breaking height. For the standard wave it is *one foot*.

All waves of the lower heights behave in similar ways, and keep time with each other and with the normal or ruling wave.

But whenever circumstances, either under water or above water, such as wind and storm, or rock or ship, or one wave interfering with another wave, tend to push the wave higher up than this normal height, order and time-keeping may be destroyed. The wave then breaks, its parts are separated, and they spread abroad.

When a wave breaks, order and time-keeping are destroyed, rule ceases to be obeyed; the particles of water go each one its own way; the union under rule and order which constitutes a wave-community ends; the drops of water going each its own way—it becomes chaos, anarchy, disorder, ruin; the wave broken up disappears for ever; the dead water exists, the living wave is gone!

How and why all this takes place and ends in wave destruction, and often in shipwreck, I cannot explain until I have gone further and deeper into the question, and shown you what is the rule and order which governs each individual water-drop, under the surface, and the sum total of which make up the wave-mass.

3. *Under-Water Wave-Motion*.—The waves which we see on the surface of the sea have forms of beauty, which this diagram shows; and graceful motions, which this diagram measures; and their dances keep time, which this time-table tells; but all we see on the surface is semblance rather than truth.

What is happening under the water-level is quite different from what is seeming to happen on the water-face.

On the water-face, the wave seems to glide slowly or rush rapidly along one way; say, from the left on towards the right. Our model wave, with a running speed of near 10 miles an hour, rushes past with an impulse which, if it were real, would crush in the side of a powerful ship. But it does not crush or injure it. The water under the surface does not go past with the wave 10 miles an hour. It merely swings gently fore and aft, swells gently up and down, and remains in much the same place where the wave found it before it passed.

The under-water motions of sea waves are most instructive, and are the essence of our present study. To know what they are we must have spent years, as I had to do, in looking and searching, in shallow water and in deep water, to find out what each little round globe or drop of water in the deep sea is doing while the waves are dancing above their heads.

The result is what I have now to tell you, that each little atom of water is revolving, in a circular path, in the same regular way in which the moon goes round the earth.

During a long wave, each drop of water makes a slow revolution in the same time in which the wave travels its own length; and during a short wave it makes a quick revolution in the shorter time of the wave transit. Under a high wave each drop of water revolves in a larger circle, and under a low wave in a less circle, but always by law and order, just as a planet round the sun. It is the study of these laws, and the knowledge of these facts, that must teach us the nature of our ocean waves, and how we have to deal with them.

A first principle in water wave-motion is, that "the sea is full." This is little or ill understood. Even "great authorities" are misled and mislead others by neglecting this. They talk and teach about water and water lines and water streams as if they were plastic, accommodating, retiring soft groups, that were ready to take any shapes and make room for any other shapes and bulks, and give place to the intrusion of any other sort of body, if not too large and bulky to find room for.

On the contrary, pray remember that "the sea is full," and that there is no room under the surface for anything more than is there already; that is the first principle of complete wave-knowledge.

The first consequence of this principle is, that you cannot make room for a ship or for a mass of water, under the surface of the still water, except by lifting an equal mass out of the water, and setting it up above the water-level. One can only enter in by turning another one out. Place must first be found for one to be turned out of before another is turned in.

When a ship is launched from the slip on to the open water, an amount of water equal to her own weight, and equal in bulk to her

room in the water, is removed from below, and is absolutely laid in a heap on the top. The same is true of the water in a ship's way when she moves. Every atom of water in her way must have room for it found above the water-level. If the water be shallow and narrow, the water heaps up so high that it overflows all its bounds. If the water is wide and deep, the heaped up water on the top is spread out further, faster, and wider, and in the deep sea the displaced mass spreads out so fast and far and wide as to fill up so low a place in so thin a layer as to be scarcely visible, and this is the reason why this now settled fact was so long unknown, and may still be misunderstood or mis-stated. All the water removed out of the way of a sailing or steam ship must find room on the top of the sea, for there is no room left below.

A second question rises here. What will happen to a still, full sea, if, by any huge force, a mass of water were lifted off out from its level face? The first answer is, that some of the water below would spring right up into the hollow. The next answer is, that some of the water left around would tumble into the hollow. That is true, but more must follow. That is not enough to fill the void.

To fill up the void, some other void must be made elsewhere! The water cannot rest around a hollow till water has been fetched from some other place, far or near, to fill up the void; so, where a void is made, we must seek far and wide for means to fill that void.

Now, we have two results of any action on the face of still water. 1. A heap of water added cannot stay, it must go away and find a new place elsewhere. 2. A hollow scooped out of the water level cannot remain there; enough water to fill in must be sent there from elsewhere.

A water wave is merely an engine or mechanism or apparatus for doing this work of restoring the disturbed water-level. It does its work admirably, and we have now to see how the storm stirred up by wind is undone and set right again by the waves after the storm goes past.

I begin with a hollow scooped out from the surface of still water. This hollow is filled from opposite sides, by waters falling contrary

FIG. 6.
Surface water scooped out.

FIG. 7.

Falling in. Filling up. Falling in.

FIG. 8.

Falling in. Full swing upwards. Falling in.

FIG. 9.
Oscillating.

FIG. 10.
Oscillating and spreading out.

waves. These opposite waters meet, strike, rise up, and form a central heap. This heap falls, fills the hollows it had left on either side, and they, thus filled, also heap up in pairs. Two more heaps fall in on two sides, leave two more hollows, which are, in turn, filled by meeting and clashing heaps. Thus there comes the odd numbers of three waves, five waves, and seven waves, so well-known to sailors as the groups of the sea. There is the one central largest wave, then two smaller ones on each side, sometimes accompanied with more smaller still, making five, or even two more, equal seven. (See Figs. 6, 7, 8, 9, 10.)

4. *Forces and Speeds of Water in Waves.*—Happily for us there are one or two simple principles of universal motion, expressed in formal laws by Sir Isaac Newton, which enable us to measure water motions just as he measured planet motions. His law of the apple falling from the tree is all we want, only he did not tell us how, after the apple fell from the tree, it was to get up there again, and that is what we have to settle. We readily see how the apple falls, but even Sir Isaac Newton did not accurately show how to get it up again.

Hydrodynamic science or water motion has this great aim—to settle the relations of height, depth, speed, time, and force.

The first law is called the law of height due to speed, and speed due to height. The law is as follows:—

The fall of a drop of water through 1 foot of height is done in a quarter second of time. The speed produced in the water by this foot-fall is 8 feet a second, or over 5 miles an hour.

The fall of a drop of water through 4 feet of height is done in half-a-second of time. The speed produced in the water by this fall is 16 feet a second, or over 10 miles an hour.

The knowledge of this simple fact enables us at once to settle the following points:

A surface wave a foot high above the level, if falling free would take one-quarter of a second to fall, another quarter to get up again. Also, if it had to go down into a hollow of a foot deep, and to come up again, it would take two quarters more. Thus a wave a foot high with an equal hollow might be expected to accomplish its work in four quarters of a second. This is what it does in our standard wave, with some modification in manner.

The modification in manner of fall by wave-motion is what is called the principle of isochronism. Our standard wave has the remarkable quality, that whether it falls from 1 inch high, or from 2 inches high,

or from 10 inches high, it occupies just the same time, viz., 1 second to complete the wave.

The principle of isochronism is this—that if you confine a force and apply it in such manner that you can vary it just in the proportion of the work to be done, you will do the more work in the same time as the less work.

Now this nature wanted is the exact nature of a water column.

Take a water column, say in a glass tube, with its lower end in the water and its upper end open, now close the tube with your finger and raise up a column of water, say a foot high above the level, then open the top of the tube and let the water column descend, and mark what time it takes; next raise only 6 inches, keeping everything else alike, and the descent through 6 inches will take the same time as through the foot.

The reason is this—the tall water column had twice as far to go, and twice the work to do, but it was twice as strong from its double height, and so did the double work in the same time. Wave heights are water columns—before they get down to or below the level, they must move the water under them out of their way—that is their work. When twice as high they do twice the work, and do it in the same time, all else being equal.

The next law I will call the law of equality all round, or if you like Greek words better than English, I will call it hydrodynamic homology.

I mean that this speed due to height in hydrodynamics, applies equally to water motion in all directions. Thus in the hollow of a wave, the water below the level pushes upwards as fast and as far as the water above the level pushes downwards, and does its work in the same time.

I next mean, that under a wave or water column a foot high, the water will go forward with the speed due to the height, just as well as upwards; and backwards just as much as downwards.

Without going into further detail I merely wish you to notice, that with these units in your mind, of 1 foot high, one-quarter second time, and 8 feet a second of speed, you can always measure what a mass of water is doing when it drives another of its own size anywhere anyhow.

Now surface waves are merely masses of water displacing one another successively, in place and out of place, by these few simple laws—of due height, due depth, and due speed—moving and keeping time in isochronic columns, and distributing moving force equally up and down, to and fro, in settled direction determined by the moving cause.

I took the scooped-out wave first, because that is the type of what I call the oscillating wave. The heaped-up wave is quite of another type, which I call the travelling wave or wave of translation, or, as it is sometimes called, the carrier wave, or the solitary wave. A high heap of water, let into or set up upon the top of still deep water, does not create a family group of waves. It remains a single solitary wave; it has no oscillating or backward and forward motion; its

motion is all one way. It is the nature of wave to which we give the name of "swell." It is much longer and faster than the surface waves, and its action goes deep down into the water, and reaches to the bottom, while the action of the other waves stays near the surface. Hence we call it "ground swell."

Now both these classes of waves, the wind waves and the ground swells, perform this function, they restore the equilibrium of the water. The hollow made by the scooping action of the wind is spread out in a thin layer, all over the top of the water, as far as the wave can reach; while the heap raised up by the wind is also rolled out into a thin film and spread all over the top of the water. But the solitary wave or ground swell performs a very different function. It carries off the heaped-up water to far off seas and shores, and spreads it all over the sands and shallows, where it expends its force in heaving up sands and rolling up pebbles and turning into fragments the rocks on the bottom of the shores of the sea.

The effects which these motions under the surface and on the surface produce on the ship, which is afloat upon and within the body of these waves, is what we must now seek.

What we have chiefly to keep in mind is that on or near the wave-crest the water in the wave is flowing forwards; that in and near the wave-hollow the water is flowing backwards; that in and near the middle of the wave-front the water is flowing upwards; that in and near the middle of the wave-back the water is flowing downwards. (See Figs. 11, 12, 13.)

FIG. 11.

FIG. 12.

FIG. 13.

We have next to bear in mind that a water-borne ship will rest on the summits of these water-columns.

FIG. 14.

Pair of Hollows. Pair of Heaps.

FIG. 15.

FIG. 16.

FIG. 17.

Water Motions in Waves along the Circular Paths of Water Particles.

Half wave Heights.	Pressure per square foot.	Speeds of water motion.
1 ft.....	64 lbs.....	8 ft. per sec.
2 „.....	128 „.....	11 „
3 „.....	192 „.....	14 „
4 „.....	256 „.....	16 „
8 „.....	512 „.....	22 „
16 „.....	1,024 „.....	32 „

Thus, therefore, the waves which cover the surface of the sea are masses which seem to fly hither and thither, and keep exact time, and seem to flow on with high speed. But this is an appearance only; the reality is that the masses of water remain in the same places or change only through a small range, while the waves in shape seem to fly afar. In each portion of one wave the water-particles are going each around in its own circle with a uniform known speed. Through one quarter of its cycle it goes upwards, through the next quarter forwards, through the third quarter downwards, and through the last quarter backwards to its old starting-point. Then begins a new cycle of the next wave.

These phases deserve careful study on the large diagram. (Plate XXXV.)

It is to these wave-motions of the water particles that we must pay careful attention if we are to create ships which shall suit the motions of the waves, and which shall neither disturb the motions of the waves needlessly, nor be themselves needlessly disturbed by them.

Monday Evening, June 9.

VICE-ADMIRAL E. GARDINER FISHBOURNE, C.B., Vice-President,
in the Chair.

PART II.

At our former meeting I limited myself to the investigation of the origin, nature, and effects of what I called surface-sea waves, as these are the most common and most visible on the ocean in storms. I will now proceed to the examination of another class of waves, quite different in nature and effects from surface-sea waves, although both may equally have their origin and do their work in one and the same storm.

The other class of waves may have several names—

Waves of the deep.

Ground swell.

Rollers and breakers.

Earthquake waves.

Tidal waves.

Cyclone waves.

It is essential to understanding this class of waves to make it clear in our minds that the two classes are quite different in all their phenomena, although the same laws of hydrodynamics govern both, and they may often have, or seem to have, the same origin. Each explains the other not as its like, but as its contrary.

As we have already seen, surface waves may appear in groups—a central one, two side ones, two more, and two more, diminishing outwards. (See Figs. 6, 7, 8, 9.) They may also have one leader and

FIG. 6.

Surface water scooped out.

FIG. 7.

Falling in. Filling up. Falling in.

FIG. 8.

Falling in. Full swing upwards. Falling in.

FIG. 9.

Oscillating.

FIG. 10.
Oscillating and spreading out.

a following. (See Fig. 10.) But I have now to introduce to your notice a wave of the deep, with no leader and no follower. Hence he is sometimes called the solitary wave. This wave of the deep

Standard Deep Water Wave.

6.28 seconds time.

Speed 32 feet''.

Limiting wave height = Still water depth.

Height of wave-crest above water bottom, 32 feet.

FIG. 21.
Shape of Ground Wave.

FIG. 22.
Water Columns in
Ground Wave.

FIG. 23.
Water Mass moved during
Wave Transit.

travels with great speed, from 10 miles an hour in water 6 feet deep to 600 miles an hour in ocean depths. (See Figs. 5, 21, 22, 23.)

This wave of the deep carries any force committed to it to any distance in short time, and delivers it up at that distance entire, with only the percentage due to imperfect fluidity of water. Hence I have sometimes called this "the carrier wave."

This wave leaves no hollow, has no follower; it finds the water still and leaves it still; it does not repeat itself. This wave lifts every particle of the deep beneath it a little upward, carries it a good deal forward, then lays it gently down again to rest, but in a new place; and it does this to every particle of the deepest water over which it passes. Hence from this power of water-moving I have called it "the

"wave of translation." Because it does its work right down to the bottom, it is also called "the ground swell."

This wave as a carrier will take the forces of a storm or a hurricane from any part of the sea with a speed much greater than the storm itself, and will deliver them on a distant sea-shore long before the storm itself reaches that shore.

The following is a table of the speeds with which a wave of the deep will carry its force and do its work afar over the ocean.

Table of Deep-Sea Waves.

Deep sea.	Carrier speed.
8 ft. deep.....	10 miles an hour.
32 " 	20 "
128 " 	40 "
512 " 	80 "
2,048 " 	160 "
8,192 " 	320 "
32,768 " 	640 "

If an earthquake sent up its force from the bottom of the sea in a great wave to the top, and the depth of the sea were 100 fathoms, this water-wave would carry the effect along the deep at over 80 miles an hour and would deliver the equivalent mass of displaced water in a destructive flood over a shore 1,000 miles off twelve hours afterwards.

Transformation of Waves.

Model Surface-Sea Wave transformed into Model Deep-Sea Wave.

How a surface wave, created by the force of the storm, is to be transformed into a ground swell, and so carried away to a distance, remains now to be examined.

Let us select for our first experiment the model sea-wave already given in our table.

Model Waves.

	Time.	Length.	Height.	Speed.	Volume.
A....	4".....	57·12....	2 ft....	14·28....	57 ft.
B....	3"·1416.	50·26....	2½,,....	16·047..	57,,

A is the sea-surface wave; B is the deep-sea wave nearest to it. The two are of nearly equal volume. B is the faster and the higher and the shorter.

What is necessary to transform this surface wave into this ground swell is this inevitable condition, "that the water shall shoal up from the bottom to less than eight feet deep."

When this happens, what was a negative wave will have its hollow below the surface filled up by the upward pressure of the rising bottom. It will cease to be hollow. It will have become a ground swell, and have all the characters of a wave of translation. It will have the same moving mass as before, and be slightly faster. But its speed will thereafter increase and diminish with the change of depth.

From our table of surface waves, let us take another longer and faster wave.

Another Wave, transformed.

Time.	Length.	Height.	Speed.	Volume.
C 9"	289 feet	8 feet	32 feet	1,156 feet.
D 6"-28	201 "	12 "	32 "	1,206 "

C is the surface-sea wave taken from the table. D is the nearest deep-sea wave of like speed.

201 feet is the wave-length due to that time in 32 feet depth of water, and 32 feet is the *depth of water* for the wave of 32 feet speed. The resulting waves are nearly equivalent.

The result of this transformation will be that the swell wave will retard its motion in 18 feet deep to 24 feet speed, and will accelerate its motion in 50 feet of water to 40 feet speed. That, in the shallower water, its height will rapidly increase, and in the deeper water will rapidly diminish, while the wave-length will diminish and increase in converse proportion.

One Solitary Deep-Sea Wave.

Time.	Length.	Speed.	Deep.	High.
20"-42	2,122 feet	104 feet	338 feet	30-528 feet
Volume. Translation mass. Tons.				
32,260 feet. 96 feet 924 tons.				

This solitary deep-sea wave is an example of the important influence of depth of water, on the speed and length and mass of a wave. A surface-wave of 20" time would be only 1,428 feet long; this is 2,122 feet long. The speed of the surface wave is only 71.4 feet a second, and of the deep wave is 104 feet a second. The waves, if of like height, would differ in mass nearly as 2 to 3.

TABLE II.

Table of Deep-Sea Waves or Ground Swell. Calculated on 32 feet as Standard.

Sea depths.	Wave-lengths.	Wave-time.	Transmission speed.
Feet.	Feet.		Feet.
32	201	6"-28	32
50	314	7-85	40
72	452	9-42	48
98	614	10-99	56
128	804	12-56	64
162	1,016	14-15	72
200	1,256	15-70	80
288	1,808	18-84	96
338	2,122	20-42	104
450	2,826	23-45	120
512	3,216	25-12	128
648	4,076	28-31	144
722	4,536	29-82	152
800	5,026	31-41	160

The comparative study of Table I of surface-sea waves with Table II of deep-sea waves will show the wide difference between the two in time, speed, length, and nature.

The surface-sea wave is comparatively short and high. The deep-sea swell is long and low.

The surface-sea wave of 4" has a speed of 14.28 feet. The deep-sea swell of 3"-14 has a speed of 50.26 feet.

The mass of water in a surface-sea wave of 4" may be 200 feet. The mass in a deep-sea swell, of like time and height, may be 700 feet.²

Under-Water Motion in Deep-Sea Waves.

The remarkable characteristic of under-water motion, in deep-sea waves or ocean swell, is that the motion is all one way.

In deep-sea waves the motion of the water-particles is forwards, in the way the wave is going. This is why it drives drift from the bottom of the sea towards the shore, and there heaves it up.

An up and down motion is combined with this forward motion, but there is no backward motion.

The motion of the water is, as it were, a semi-circular leap forward. (See Figs. 21, 22.)

FIG. 21.
Shape of Ground Wave.

FIG. 22.
Water Columns in Ground Wave.

This circular leap forwards and upwards is flatter near the bottom and rounder near the top of the water.. (See Fig. 22.)

¹ These numbers are the weight and volume of each foot length of the ridge.

² Reckoned for each foot along the wave ridge.

FIG. 22.

Water Columns in Ground Wave.

But the particles in the same upright line leap all at once, spring each a different height, but leap all the same distance.

The time the leap of each particle occupies is the time of the wavelength. All, in one upright column, start at the beginning of the wave and alight at the end in perfect rest, and remain there until another wave follows.

This leap is the motion of translation caused by each deep-sea wave on ground swell. There is a permanent change of place in the water; not a passing change.

The distinctions between the under-water motions of surface waves and of ground swell are best expressed by saying that, while the water particles in the surface wave move in complete circles of rapidly diminishing size, the water particles in the deep-sea wave move in half circles, gradually flattening, but not diminishing in span, all the way down, as shown in Fig. 22.

Complications of Waves in a Storm.

If there were only one single group of waves in one steady strong breeze, I do not think that their growing size, however great, would seriously endanger a good ship. It is the complication of different sets of waves, coming from different sources and in quite different states, which produces confusion, chaos, and danger. A sailor knows full well how to lay his ship's head for a single set of waves, and is not afraid of their behaviour.

To understand a complicated sea, let us begin by conceiving a long low deep ground swell to have set steadily in upon a smooth sea. The waves are long, low, and gentle. We are in 48 fathoms of water. Waves, 6 feet high, swell gently upwards, 600 yards long, from crest to crest, and pass us, three in each minute. There has been a storm somewhere. The long, low waves of the swell are travelling 60 miles an hour; so that a storm, 360 miles away, may be coming towards us, and, as storms travel from place to place much slower than these waves, we have some hours to prepare. If we are in the Bay of Biscay, where I have watched them, these swell waves may be coming from the north-west.

By-and-bye, a smaller second set of waves sets in, shorter in time and space, from the north, and crossing the ground swell at four points, we have one set of wave-ridges overlapping the others and many more

in the same space. This is a much nearer storm, as these surface waves are fresher and travel much slower than the ground swell. They are five to a minute, and over 600 feet long. They only travel 32 miles an hour. They come from a storm much nearer.

We have now a ground swell of waves three to a minute and 600 yards long: and also a series of surface-sea waves five to a minute and 600 feet long. If they were all in one direction their combination would be simple, as the surface waves would move along the ground swell just as though it were still water. But as they cross at a difference of four points of direction their crossings are more complex, and not easily seen in one plane.

Now the storm has come nearer, the wind blows from the north-east with violence, and the waves are now shorter, sharper, and quicker. The third group of sea waves are square across the second, and at four points from the ground swell. It is these last crossing the others, being crossed by them, changing direction with the chopping wind, and whirling about with the eddies of the blast, and over-riding the two previous series of waves, that make confusion twice confounded.

Storm Breakers and Shore Breakers.

Up to this point we have had the storm nearing us and gradually growing, but we have not yet had the worst of it.

So long as waves are of certain limits in size, even three or more discordant groups might co-exist without dealing destruction to ships or to each other.

But when we pass the breaking point, destruction threatens equally the waves themselves and the ships they carry. It is necessary now to study wave breaking: whence it comes, and what it means.

The Shore Breaker.

The shore breaker is the deep-sea wave rushing to destruction; to understand this we must go back to the beginning.

I told you that the surface of the sea has a skin covering—of great density, very tough, but very thin. On it the gentle winds make wrinkles or skin waves—the biggest wrinkle is about 2 inches broad, and it requires a force of some 4 lbs. to the square foot to tear asunder the skin.

I asked you to conceive of water in the sea as though it were so much liquid stuff stowed away in india-rubber sacks all set up against each other, upright in rows all pressing each against the other. This allows these bags to be squeezed out of one shape into another, but without any of the water which fills them ever getting out of any of these bags. There is no loss or waste so long as this condition is kept.

Wave breaking is really the breaking up or the bursting open of these water bags. When the bags are burst open, the drops of water no longer hang on by each other. Every drop rushes off on its own wild way; time in motion is no longer kept—all bond of order is

gone; thousands of atoms of water are tossed about in wild confusion.

The reason of this I will now show in the deep-sea wave. We know the speed of a deep-sea wave, it diminishes in a given ratio to the diminution of the depth as the water shoals towards the shore. In 48 fathoms of water our deep-sea wave is going 60 miles an hour, and may be 6 feet high. In 20 fathoms water it is going 40 miles an hour, and its height is above 12 feet high, and has shortened to half its length. In 9 fathoms water our wave-speed has gone down to 30 miles an hour, and its height gone up to 25 feet. In 6 fathoms water the wave will be 36 feet high, and from that point on towards the shelving shore there will be one continuous breaking cataract, pouring the whole volume of the water it contains out of the burst bags which contained it until every drop has been dispersed, and all of them laid out in a great white foam along the beach, or thrown up against rock or beach or breakwater with a violence which will make the deluge spring up 30 to 40 feet high, dealing out destruction or send the frittered spring in magnified recoil 60 or 100 feet up on the cliffs.

That is what I call a breaker of the first order or deep-sea breaker. The reason of this destructive violent rupture and dispersion is this: the wave form has a certain fixed speed of its own; that speed in deep-sea waves is taken from the depth of the water; but the wave-speed is quite apart from the speed of each atom of water. The wave has its own speed, but the water has quite another and a much slower speed. While our wave was going 60 miles an hour, the water atoms in it were going less than 16 feet a second; but as the wave went on to the shallow it went slower and slower, while the accumulating mass in the shortening and rising up wave became higher and faster, and in doing so each water atom was compelled to make a higher and farther leap. At last the wave-motion showed so much, and the leaps of the water particles grew so high, and they sprang so far, that the wave-bags burst, and each water-particle going higher and further than the wave could follow it there was an end of common movement and common bond, and each water-particle rushed with its own speed and force wildly spent against whatever obstacle, rock, ship, cliff, or beach came in its way; the water became a wide-spread flood, and the wave had ceased to exist.

The Storm Breaker.

That wave we have just followed from the deep sea may have been originally a surface-sea wave, generated by wind far away in the fathomless ocean, and slowly transformed by shallowing depth into a wave of the deep or ground swell.

But there are also breakers on the surface of the sea in waves which never reach the shore, nor go so deep as to feel the bottom.

How they come to break we should now examine. For the study of this subject we may take a wave of each kind. (See Fig. 11.)

A Surface-Sea Breaker.

FIG. 11.

A Deep-Sea Breaker, or Ground Swell Breaker.

Waves which feel the bottom of the sea only break by shallowing in the following fashion: as the water shallows they shorten, as they shorten they rise. When the shallowing depth and the rising height of wave become equal, breaking begins, and goes on as long as the water shallows. If it deepens again, the wave will cease to break, will diminish in height, will increase in speed, and grow in length, and resume its first speed and bulk.

The reason of this equality of height of breaker and depth of water is, that the speed of the wave depends on the depth, while the speed of individual water atoms depends on the height, and both in such manner that when depth and height become equal, the water speed equals the wave speed, that is, the condition of tottering equilibrium, after which the slight excess of height of wave or diminution of depth upsets the balance, and the faster motion of the water atoms removes them out of the wave, and severs the bond between it and each other. The wave diminishes rapidly as the water leaves it and floods the shore, and once the water-particles are dispersed, and their time-keeping movement and wave-line bond is broken, the water becomes chaos and the wave ceases for ever. (See Figs. 5, 21, 22, 23.)

FIG. 5.

Standard Deep Water Wave.

6.28 seconds time.

Speed 32 feet".

Limiting wave height = Still water depth.

Height of wave-crest above water bottom, 32 feet.

FIG. 21.

Shape of Ground Wave.

FIG. 22.
Water Columns in
Ground Wave.

FIG. 23.
Water Mass moved during
Wave Transit.

How the Wind Creates Breakers.

The direct pressure of the wind on a square foot of wave surface is—

- 1 lb. for 20 miles an hour.
- 4 lbs. for 40 miles an hour.
- 9 lbs. for 60 miles an hour.

This is the result of my many exact measurements; it is more moderate at high speeds than the measures of others, which I think arises from errors in the instruments they used, and to these errors my instruments were not liable.

One cubic foot of salt water weighing 64 lbs., 4 lbs. is the sixteenth part of the weight of a cubic foot of wave. This force could communicate a speed of 2 feet per second to 1 foot of water in one second of time. Supposing then a surface-sea wave 4 feet high and 64 feet long to be attacked by such a wind, and taking the mass of 1 foot section to be 128 cubic feet, it would have a speed of 2 feet a second given to it in 32 seconds of time, or about half a minute, and in little more than 8 minutes it would be raised to 16 feet high, and have a speed of 32 feet a second; it might become a violent breaker, and might contain 7 tons of solid water in each foot of ridge-length, which, projected over an impediment, a ship or rock, would deliver a stroke of 20 miles an hour speed with a weight of 7 tons. If it were 10 feet wide along the wave-ridge, it would deliver a shock of 70 tons at 20 miles an hour, equal to the stroke of a railway engine collision.

Storm Waves and Stable Ships.

I think we may take it as the definition of a storm wave on the surface of the sea, as distinguished from a gentle wave or smooth swell, that the hollow below the water-level is the same depth as the heap of water is high above the level in moderate weather, and with moderate sea. But in the storm the wind drives the water-heap up to a sharp crest, which is three times as high as the hollow is deep. Thus the swell may be $\frac{1}{2}$ to $\frac{1}{3}$ of the wave-length in height without storm waves being directly created; but when this height is suddenly doubled by a sharp crest, driven up to near $\frac{1}{4}$ of the wave-length in height, the storm waves become breakers, and may be a source of danger. (See Figs. 11, 12, and 13.)

This rapid doubling of the height and sharpening of the shape by the violent wind, makes each individual wave a source of danger; but this danger becomes exaggerated by the complication of several series of waves in several directions at once, and each of these can mount on the top of the other, and so produce its own destruction as well as aid in the others.

Three causes lead to danger waves and breakers :—

1. The wind sending up the wave crest to a height two or three times greater than the hollow.
2. One wave summit rising on the top of another.
3. The water shoaling under a ground swell.

We have now seen enough of the shape of these waves, and learned enough of their under-water motions, and measured sufficiently the force of the wind on the waves, and the moving power imparted to the huge moving masses, especially when breaking, to be able to appreciate their effects on ships.

"The Rock" (Fig. 2), "The Raft" (Fig. 1), "The Ship" (Fig. 3), are the three types we have taken as representatives of "smooth-water stiffness," of "rough-water stiffness," and of the "storm stability," of which we are in search.

Take the rock of 48 feet beam, and 29 feet draft.

" raft of 64 " " " 20 " "

" ship of 56 " " " 23 " "

all of like shape, and tonnage, and different proportion.

The first with its weights very low.

The second with its weights very high.

The third midway.

The first would be steady and stiff, and would stand upright under canvas both in rough and smooth water. But it would be uneasy, and in a storm would be struck heavily by violent waves without

yielding, and might therefore suffer great damage in a storm by injury done to her structure; she would be struck like a rock by the sea.

The second would be steady and stiff and upright in smooth water, and stable in gentle waves, but would roll dangerously in a beam sea, would take in on deck the entire volume of storm sea waves, and might capsize.

The third ship, well trimmed, might avoid the dangers of the other two by good proportion and wise shape, which we shall now seek.

On Ship Shape.

That a good seaworthy safe storm conqueror may be constructed with high storm stability and gentle easy motion, so as to be neither rock nor raft, I can venture to assert as the result of many years of experience and observation. I cannot claim originality in such forms, as they are a tradition from the former generations of seaworthy ship-builders, and were expounded by the most distinguished of our philosophers and mathematicians. But I have arrived at their conclusions, although proceeding on quite different data, and following quite other methods of research.

In order to find out the most perfect form of ship for storm stability, I take a form of no stability, and then I seek to give it only that kind and those degrees of stability which I want.

The typical form of "No Stability" is the circle. A circular body, or barrel-shaped midship section, has the wonderful quality of absolute neutrality, of perfect indifference to attitude, and is equally endowed with stability or instability in a smooth calm or in a raging storm.

This quality of perfect neutrality in all seas is just that quality which enables us to handle it as we please, and give it just the degree and kind of stability we want.

If we take this round or barrel form and place in it, without change of shape, a very small portion of ballast, this small bias will ensure the circular form remaining always upright, even on the most troubled waves.

Supposing then such cylindric midship body to be weighted with sufficient ballast to bear up under the pressure of sail, by ballast alone, the waves would roll all around it without disturbing effect, excepting the two effects of rising and falling, pitching and scending. Its masts would stand up steadily under due pressure of wind, only inclining over to the due angle and press of sail.

But this shape and trim would have one fault. We do not wish a ship to stand upright, or to have a fixed and changeless inclination on a heavy sea. We wish our ship to careen gently over with the slopes of the swell; we wish our deck to conform gently with the slopes of the waves; we do not wish it to follow the violent changes of storm waves into their extreme and dangerous slopes; we wish our ship to stay half way between.

This medium motion we must now try to give our ship so as to stay equidistant from rock stability and raft stability.

The form which unites and reconciles these opposites we obtain as follows:—

Take a circular midship body of no stability—place it afloat at the intended draft of water—arrange all the weights so that the centre of weight shall lie in the centre of the circle—place all the heavy weights at the *nearest* convenient place to the centre of the circle—place no weight further away than is indispensable to its use.

This circular body is now afloat, carrying all its own weights, but entirely free of stability of any kind (see Fig. 18).

FIG. 18.

FIG. 19.

FIG. 20.

Next, take two triangular forms, which I call shoulders— S_1 and S_2 , Fig. 19—add these two areas of section to the circular section, then place low down in the hold their equivalent buoyancy in mass of ballast.

Thus, two sources of stability have been given to the unstable circle—shoulder stability and ballast stability, and an equal quantity of both.

Now, this shoulder stability, being only half of the whole stability, will give the ship easy motion on the waves and with them.

And this ballast stability will give the other half wanting to keep the ship vertical and maintain the action of the wind on the sails.

Thus we have halved each of the kinds of instability to which the ship is liable, and have provided the complete whole of stability the ship requires, and thus we have minimized the movements of the ship with the sea and minimized the careening power of the sails.

The size of these shoulders of the ship and the place of the ballast are matters of exact calculation, and must be suited to the purpose of each ship.

But, in modern steam ships, there are so many large and weighty

masses of matter, the wise placing of which should be at the disposal of her designer, that no difficulty in disposition of weight should require the ship to be burdened with valueless weight. Engines, boilers, water, and fuel give ample ballast, but they are sometimes unwisely placed, and do harm.

It will be readily seen how this form, with its opposite halves and natures of stability, will have compensating natures of force within itself, preventing either motion becoming exclusive or excessive, and, therefore, the tendency to oscillation through large arcs from internal causes is minimized.

It will equally be seen how this circular form evades all the forces from causes external to the ship tending to give it rolling motion. In all the classes of waves, we see that the under-water motions are circular. If, therefore, our ship were of an angular shape, or if it possessed the strange deformities called bilge keels, we could see how the circular vertical oscillations of water-masses in wave-motion would strike on these projections, with violent concussion or with accumulating friction, and how the waves would thus first communicate to the ship violent rolling movements and then, by contrary violence, bring it back to rest, thus performing much useless work and involving much waste. But the stable circular form has neither an instrument to disturb the free oscillation of the water in its wave circles, as they surround and embrace its body, nor has it any protuberances, corners, or flat boards upon which the revolving water masses can deliver their blow.

This form, therefore, has no internal source whence to obtain rolling and dangerous motion, nor has it any external instrument by which to impede or take up any of the storm forces raging around.

Conclusions.

I trust I have now answered all the questions I undertook.

1. A storm is that state of the sea where waves, which had equal height and hollow, have been driven so high that the height above the sea level is near threefold the depth of the hollow.

2. Smooth water on sea is not necessarily level water, but, so long as the height and hollow of the waves remain equal, it may be reckoned smooth water.

3. Stiffness is the ability which a ship shows to resist the tendency of wind and sails to incline it over from the water surface.

4. Stability is the ability a ship shows of not taking from the water the rapid changing attitudes which the water itself assumes in storm waves.

5. A storm is created on the surface of the sea by the excavation of a hollow from the level-water surface, and by the piling up of this excavated mass in the neighbourhood of the hollow. These two are always of equal volume. The force of the wind measures the height of these waves.

6. Smooth water returns after a storm, first by the descent of the wave crests from their threefold height to their equality of height and hollow; next, by the spreading of the heaps and hollows more and

more wide, until they exhaust their force on water friction, or til they break up on the sea shore, or until they create other waves, which take off their force to a great distance.

7. A stable ship is made by moderate beam, due depth, and by such shape and weight as neither to oscillate from internal cause nor to suffer injurious movements from without, which stands up without becoming uneasy, and leans over gently without jerking against the waves.

8. A ship is made stiff either by much beam or by much bottom weight; the least quantity of either that fulfils the useful purpose of the ship, is the best.

9. The nature of surface-sea waves, as distinguished from the nature of deep-sea waves, is that they do not agitate the water much below the surface, however violent their motion may be on the surface. A wave 36 feet long, even if 9 feet high, would produce scarcely any motion 18 feet down; the motion of such a wave 36 feet long would not ordinarily be more than 4 feet, 2 upwards and 2 downwards, except in a storm. While each water particle moved 2 feet up and 2 feet down, it would also move 2 feet forwards and 2 feet back, thus performing vertical circular motions with steady speed. While the wave seems to fly onwards, the water really remains going round in a place either fixed or slowly changing.

10. The nature of breaking waves is this: that whenever the force of the wind is so great that the separate particles of water sent up into the summit of a storm wave receive a more rapid motion than the wave form already has, the particles moving faster than the wave, upwards and forwards, leave it, take each their separate way, and the wave is dispersed, diminished, perhaps destroyed. Or, if one wave overtops another, the like effect takes place.

11. The ground swell differs from the surface wave in the fact of the motion of its particles descending all the way down to the bottom where they go as far forward as at the top; they go all forward and none backward; there is no hollow below the water level, and each wave is a large heap raised above the standing level of the still sea. They break, whenever the depth of water equals their height.

12. Storm waves are surface waves which, instead of having equal heights and hollows, have the water sent up by the force of the wind to a sharp crest, which breaks when about three times as high as the hollow; and, also, those waves which, by the force of wind changing direction, are driven to ride on the top of each other, and are driven over and clash and mutually destroy each other or the ship they strike rudely or which rudely strikes them.

13. A crank ship should not exist; it generally comes of narrow beam, or too great depth or top weights; it inclines far over with light wind or none; it makes long and heavy swings; it is dangerous, and only high freeboard can save it. Bottom weights lowered down or sent in are the common cure.

14. A stiff uneasy ship is the contrast to a crank ship. I have sometimes seen a crank ship made the better of the two; the crank ship yielding slowly and gently to the waves, and rolling too much,

but easily; while the stiff ship, with its own inside weights, was jerking with violent, short quick blows, from side to side, in collision with the waves. The removal of weights from places where they give and get violent motion to those places where they will move more slowly round a stable centre is the cure.

15—22. All these questions are already solved by the shape of ship shown in Figs. 19 and 20, and the distribution and stowage of weights as near to the centres shown as is consistent with the purposes of the ship must govern the rest. The evils we cannot avoid we may at least *minimize*.

DESCRIPTION OF THE FIGURES AND DIAGRAM.

Fig. 1 shows the midship section of ship which is stable in smooth water and unstable in a heavy sea.

Fig. 2 shows the midship section of ship which is too stable in all weather, and requires to carry much heavy weight low down. It is never easy, gentle, or lively, and is always fighting violently with the waves.

Fig. 3. The ship shape is always easy and lively, stable and gentle, having the exact measure wanted of surface stability for smooth water, and of uprighting stability for rough seas in a storm.

Fig. 4 is the standard surface wave. Each particle of water on the surface moves once round in a vertical circle during the same time while the crest of the wave moves forward. Just as a wheel goes forward while each spoke goes round, so each particle of water goes round a circle the way the wave is going in the same time in which the wave goes forward through its own length.

The Diagram (Plate XXXV), shows the details of water motion and of wave motion in a model surface wave, from which (as also from the standard, Fig. 4) the other waves may be calculated and measured. See Table I of surface waves.

This Diagram has the vertical columns of still water shown by upright lines. These lines sway back and forward at bottom and top of each wave. The water columns lengthen and shorten, while the top of each water column goes round a circle and at a certain depth below stands still. The water columns sway back in the hollow of the wave and swing forward on the crest. The motion of the wave is uniformly forward, the motion of each water-particle of the surface is uniformly round in the circle, and the rise and fall of the water corresponds exactly to the times and heights of the uniform circular motion. In short, the motion of each single water-particle corresponds to the motion of the hand of a clock, and keeps time with equal truth.

Fig. 5 shows another wave of quite a different nature from the surface wave. It is called the deep-water wave as distinguished from the surface wave, because the water in it moves as much at the bottom of the water as at the top and always forward, instead of backwards and forward.

It is called the ground swell because it always feels the bottom and tells the eye which can read its meaning, how deep the water is. It is sometimes called the wave of translation because it carries things forward the way it goes. Figs. 21, 22, 23 show the details of the deep-water wave.

Fig. 6 shows how surface waves are created. Wind or other forces scoop out a hollow, and the water resists, and pushes up water from below to fill up the hollow.

Fig. 7 shows the water below springing up to fill this hollow, while from both sides the water also flows in to fill it. These three meet and spring too high and fall down again.

Fig. 8 shows the water rising full swing upwards above the level forming a heap, while the two sides whence the water flowed into the first hollow are now emptied out, and two hollows remain on each side.

Fig. 9 shows a new state of things, results of the former. The central heap falls; the side hollows are filled from below.

Fig. 10 shows a stage further on. One central scoop, a couple of heaps on each

side, a couple of hollows formed on each side of these, and so this process goes on in odd numbers of waves:—

One middle one.
A pair of side ones.
A second pair of side ones.
A third pair.

Thus making:—

3 waves in a group.
5 waves in a group.
7 waves in a group.

And so on, either growing up or dying out, according as the moving force of the wind strengthens or dies.

Fig. 11 shows the surface wave with its two side scoops when it reaches its breaking height and becomes a storm wave. In this diagram is shown how the water scooped out of the hollow is piled up three times as high, and forms the summit load of the wave just before it breaks.

Fig. 12 shows how if the wind falls this wave subsides; diminishing its height till it is only the same height as the hollow is deep.

Fig. 13 shows how this equal height and depth continue until the wave disappears.

Fig. 14 shows the volumes of water moved.

Fig. 15 represents the places where they are moved to, in order to be set so as to form a wave.

Fig. 16 shows the order in which these heights and hollows must be set to form a continued series of waves in smooth water.

Fig. 17 shows the new attitudes these same masses take in a storm. The hollows remain unchanged in attitude, but the heights are driven nearer and set upright to the extreme of three times the hollow, after which they break down and become scattered.

Fig. 18 represents the form of absolute indifference, which may be called equally the form of no stability or of no instability. It is the form which the water does not disturb and which does not disturb the water—the slightest weight below its centre will keep it upright. It is a perfect float for carrying heavy weight placed around its centre (M); but is not a ship.

Fig. 19 shows how to make it a stable ship in smooth water. Two shoulders on the two sides are added to the volume of the ship. The exact measure of stability you want is given by the areas of these triangles and by the place of their centres when in the water, and thus the required measure of power to carry sail in smooth water is directly obtained.

Fig. 20 shows the shape of midship section of ship which is thus obtained. But as we have added to the volume of the ship the addition of the shoulders, we must now also add to the former load carried so much additional load in cargo, stores, or ballast. In placing this new weight we must either place it low down, so as to double the power of the shoulders in still water, or, considering it as part of the whole lading, we must lower the whole lading down to the place where it will produce a like effect. We have thus got our whole stability in two halves; one half in the power of the shoulders keeps the ship normal to the surface of the water, the other half, in the equivalent weight added below the centre, or in the whole weights lowered down, tends to keep the ship upright or vertical without reference to the water surface or wave surface. Thus, in still water both actions help to keep the ship up under canvas; in surface waves the ship is both stable, lively, and easy; in storm waves the uprighting stability steadies the ship, and the surface stability gives her easy gentle movements. Thus, in Fig. 20 we have the shape and the stowage of weights and ballast (M and B) which give equally storm stability and smooth-water stiffness.

Fig. 21 gives the shape of the deep-water wave or ground swell already described in the standard in Fig. 5, and here much enlarged. The circle in the centre represents time by the hand of a watch going round. As that hand goes up and down and round the circle, so the water surface rises and falls, and goes forward along the line, keeping true time and exact height. The times are shown in instants on the

curve, as 0, 2, 4, 6, 8, 10, 12, 14, 16 instants rising up, and as 16, 18, 20, 22, 24, 26, 28, 30, 32 instants falling down.

Fig. 22 shows how the water is moving in the deep water while that wave is moving along the surface. The water at rest is in vertical columns and these columns remain vertical throughout the wave transit. The figures above, 0, 2, 4, 6, 8, 10, &c., show how these columns march forward in the deep, while the wave on the surface glides along, as shown by the same numbers in Fig. 21, all keeping true time.

Fig. 23 shows the result left behind the wave 21 after it has passed away. All the water columns shown there have been marched forward out of their former place where they rested, and set down in a new place that length forward and there left at rest exactly as before. Fig. 23 is, therefore, a series of columns as found at rest and left at rest, and Fig. 23 shows the same series of columns as they are while on the move, under wave shape, Fig. 21.

Admiral FISHBOURNE: We are very much indebted to Mr. Scott Russell for his very clear and lucid exposition; his distinction between smooth-water waves and sea waves shows the real cause why there are such diversities of opinion with respect to the performances of ships. That has been entirely lost sight of, so ships have been compared in conditions that are totally diverse, and it is often assumed that because a vessel conducts herself well in particular circumstances, such as smooth water, she will necessarily conduct herself well in other circumstances. This is a dangerous mistake. We have never had the exhaustive examination of models when first produced, that we ought to have had. Examinations are not so extended as they ought to be; moreover, the persons carrying them out are continually changed; thus they are all learning their lesson instead of having experience and standard by which to measure.

Commander CURTIS, R.N.: I should like to make a few remarks with respect to that vessel that Mr. Scott Russell called the "Rock;" in nautical terms we should call it a half-tide "Rock." There were six vessels fitted out in Dundee or some port in the North, to go to the Yang-tze-kiang in 1864, which were called clipper barques, of great length and light draught, laden with railway iron, and I think from hearsay there were only two that ever arrived at their destination. One put in at Rio, she washed everything off the deck, rolled so that she flapped topgallant sails out of the bolt, and when she arrived at Rio she had to put bilge pieces on and to raise the ballast. I think you will recollect that when Mr. Porter the other day at the Society of Naval Architects read some interesting reports about the load line, some gentleman sarcastically remarked that the load line might just as well be on the maintop for all the use it was, and I think he was nearer the truth than is generally imagined. If you look at the papers every day, you will find, I think, that we lose on an average one ship a-day by foundering. The fact is, I suppose, there is very little stability in the way of stiffness on account of the disposition of the weights in the ship,¹ and they are really capsized in the trough of the sea. I agree with Mr. Scott Russell that the disposition of the ship's weights should be such that with her engines and 20 tons of coal, and boilers full of water, she ought to be able to stand up under her

¹ See *Standard*, May 21st, 1879. Missing ships between America and England—since 1841—number lost 145—26 missing, 80 wrecked, 6 foundered, 8 abandoned—1 capsized, 11 burned, and the rest sunk by collision.

Five new iron steamers lost this season were laden with grain, bearing out what I say, that grain laden vessels have very little stability, especially if they have compartments for *water ballast*, and those compartments empty, which I believe is the practice when laden, it tends to make the vessels top-heavy—and they are overwhelmed with the sea before they can right themselves. The paper remarks, "It seems hardly to admit of any doubt that a class of steamers have been placed in the Trans-atlantic freight business which are not adapted for *stormy winter seas*, or else there has been gross neglect in loading."—J. D. C.

canvas, I do not say in a gale of wind, but steamers going from one port to another for cargo may be reduced to 30 or 40 tons of coal, and have to depend upon the sails, in case of losing the screw, not infrequent in merchant steamers. To give a false bottom, I think makes the ship weak, and water is an objectionable thing to have in a ship, because you never know where a leak will be. The true ballast of a ship should be her engines and boilers, and she ought to be able to stand up under her canvas. I should like to say just one word about waves travelling. I know that running round Cape Horn, we often had very great fears of being pooped by the waves.

Mr. WHITE: I am sure we must all feel, in listening to Mr. Scott Russell, what a master he is of the power of popular exposition; but I think sometimes that the wealth of his illustrations makes it more difficult to say anything that is critical concerning them. If, therefore, I now raise a question as to one or two of the "standards" which Mr. Scott Russell has given, I know he will take it that I am asking for information, and not disputing his observations. I have not the opportunity which he says he has had of personally observing waves at sea; but I have had the opportunity of studying the observations made by many naval Officers in the French, English, and American Navies, and I find that the law connecting the length and period of waves is not that given on Mr. Scott Russell's table of "standards." Instead of the factor given by Mr. Russell—the convenient number for memory 3·57—I find that factor more nearly approaches the figure 5. In fact, taking the average of a very large number of observations, I find the so-called "trochoidal" theory (which would give the exact figure $5\frac{1}{2}$) is as nearly as possible confirmed. If any gentleman will turn to Mr. Antoine's long list of observations which have been recently published, he will find that having compared observations made in the French Navy, with Dr. Scoresby's observations and all the other observations on record, French writers have accepted the trochoidal law as their standard, and this makes $5\frac{1}{2}$ times the square of the period equal to the length of the wave.

Mr. SCOTT RUSSELL: What is the seconds wave?

Mr. WHITE: Five and one eighth feet. I do not mean to say that they have ever observed a wave having a second period at sea; I mean to say taking for example, waves of six seconds period, those waves would be over 180 feet long instead of being, as Mr. Scott Russell has it on his table, 128 feet long. Only to-day I happened to take up the observations made on board one of the ships which Sir Cooper Key has recently had in his squadron in the West Indies, and I found a record of waves of eight seconds period over 300 feet long. I only give you these as instances confirming my statement that the very extensive observations made in the last few years by naval officers do not agree with the standards given by Mr. Scott Russell. Then as to Mr. Russell's "pattern ship" I wish to say one or two words, from the naval architect's point of view. Mr. Scott Russell knows as well as any one that you could not possibly point to the circular cross section, those "shoulders," from which he hopes to derive such benefit, without affecting the position of the metacentre of the ship.

Mr. SCOTT-RUSSELL: I have avoided metacentre.

Mr. WHITE: I know it is avoided in terms, but it is there in fact. I am accustomed to speak about the metacentre; Mr. Scott Russell is accustomed to speak about the shoulder; we mean the same thing. But I must add that the whole effect of the shoulders is not counted up when you take account of the consequent alteration in the position of the "centre of buoyancy" Mr. Scott Russell will admit that, I am sure. The truth is when you join to a circular cross section sections which are not circular—

Mr. SCOTT RUSSELL: Of course I raise the metacentre, I assumed everybody knew that.

Mr. WHITE: Then raising the metacentre—

Mr. SCOTT RUSSELL: Gives me exactly the buoyancy I want.

Mr. WHITE: It also takes away the very admirable quality which the circular cross section has, viz., that all the external fluid pressures are then delivered through the axis of rotation. If you have joined to the circular cross section those shoulders, you must lose that quality; I have been for a good many years connected with the

designing of steam ships with very large engine powers and "disposable weights" as Mr. Scott Russell puts it. Our difficulty however usually is to get the boilers and engines into ships at all, in convenient places; in ships of war, for instance, it is necessary to place the machinery under the water line, or under the protection of the armour. It may be different in merchant ships; I do not pretend to say much about their design, but it obviously embraces other and special considerations. But in ships of war, most certainly, from not a small experience I can assert that our chief difficulty is usually to get engines of the necessary power into the space available under the necessary conditions. So that, the vertical distribution of the weights of the machinery is not a thing which helps the naval architect so much as Mr. Scott Russell seems to suppose in governing the position of the centre of gravity. On a previous occasion in this theatre I remember Mr. Scott Russell also made a similar statement as to the effect of the disposable weights of machinery and boilers, and therefore, I now take occasion to say that in our experience in war-ship-design, that is not a thing that helps us to anything like the degree Mr. Scott Russell would suppose.

As to the general character of Mr. Scott Russell's remarks I join in expressing the thanks that we feel. I think his remarks on wave motion, in the main, express the views of all the most eminent authorities who have written on the subject. Of course Mr. Scott Russell puts his diagrams forward simply as rough indications of the internal structure of waves; but I must say this, that the breakers that Mr. Scott Russell has put on the board (or what we usually call "cycloidal" waves) are not the waves which sailors tell me often produce the most extreme rolling in large ships. And further I would say that the second "objectionable" type of ship, according to Mr. Scott Russell (his "half-tide rock" type) is pretty nearly the section of many existing merchant ships; and I am told that those ships, although very deeply laden in proportion to their beam, as a rule behave exceedingly well. I am now speaking of such vessels as the Atlantic liners which would often have 27 feet of draught on starting, with 40 to 45 feet beam—a proportion of draught to beam which in ships of war is scarcely ever, if ever, seen.

Admiral SELWYN: I think, Sir, we all join in our admiration of Mr. Scott Russell whenever he rises to speak to us. His facility of manner, and his happy illustration, command attention, and give us a great deal of instruction in a very short time. As regards his observations on waves at sea, most of my brother seamen will join me in saying that one of the most difficult things to answer a man can be asked who spends a long life at sea, is—What is the ordinary behaviour of waves? One man will tell you that he never saw a wave above a certain height, and he may have followed the sea quite as long as another who has seen a great many varieties much higher. It happens perhaps to a young sailor, who goes to sea for the first time, to get into a hurricane, while another may follow the profession his whole lifetime, and never come across one. And when we do come across hurricanes, this remarkable fact takes place, that although we should like very much if we wanted to see big waves, that the wind should blow over us in one certain direction for the greater part of the time during its period of touching the earth, that is just what it never does. Luckily for ships' existence, it is always turning round, and creating cross seas, which complicate the problem so tremendously, that the closest observers will tell you that they have very rarely seen a really steady sea. I think it is rather a disgrace to the profession that we should now regard the observations made by Dr. Scoresby in small vessels, as our only standard of information on the subject. I am quite sure, from my experience in the large Atlantic steamers, that they offer to us very considerable advantages for observation. They are of lengths which I will not say in the heaviest Atlantic seas, but in most Atlantic seas, are not surpassed by the wave length. In the "City of Richmond" and the "City of Chester," two of the longest of the Inman Line—over 400 feet long—I have observed that the wave entering under the stern was coincident, as nearly as possible, with the wave parting from the bow, with a following sea, in a gale of wind, at a speed of 16 knots, and under those conditions the depth of the wave was often quite inconsiderable, compared to what might have been seen in a heavier or a longer continued gale of wind. I regard the whole question of the action of the waves as one to be subordinated to the consideration of the downward friction of

each particle or atom of water, that is to say, the power of the superincumbent water moving over the lower water, and the frictional action so set up, to retard the wave. That there is a motion forward in obedience to the force exerted by the wind no one can doubt, but this is brought to rest in very large measure, as Mr. Scott Russell has shown, by that very frictional action which raises the wave, and the trochoidal theory showing the circular movement resulting from the friction below, is the nearest approach that has yet been made to the true movement of any atom of any wave. But with regard to the height to which waves can rise, Mr. Scott Russell must give us the conditions. If it blows a gale of wind into the Bay of Biscay, lasting for a certain time, the motion may be so far communicated downwards, that the wave which would not have been a breaking wave in the Atlantic, becomes a breaking wave in that depth of water owing to the frictional effect of the immovable bottom coinciding with the frictional effect of the partially movable water, and producing a break where there would only have been a slight cone. With regard to the speeds of waves, it would be very useful if we could rule the waves in parallel lines, but I quite agree in thinking that we may usefully study the question much further than we have yet done; that it is a fair reproach that the attention of sailors has not been more devoted to what their extremely accurate instruments enable them to do now much better than before, that is, to study the behaviour of their ships in waves which will differ with every form of vessel, with every mode of disposing of weights, and also even with the skill of the captains in meeting the waves.

With regard to the shapes of vessels which give storm stability combined with smooth-water stiffness, I venture to say that we have done a great deal to weight our vessels unnecessarily. I am most happy to hear the repetition by Mr. Scott Russell of an idea which has been long present in my mind, that he was not fit to be called a naval architect who puts ballast—useless weight—into a steam ship, particularly that that is the case when we have to deal with iron and steel ships—he is not deserving of the name of naval architect, for he has not made the proper calculations or he would not have to put in useless weight any more than the boy who knows how to cut out his wooden model well, will have to put a lead keel to the vessel to keep her upright. Now I want to know from Mr. Scott Russell is it a necessary part of the higher art of naval architecture that ships should have a normal position bottom up? Is there any good reason now existing more than existed forty or fifty years ago, why a ship should not be able to turn over on her beam-ends, and if you cut her masts away, or otherwise relieve her of the reclining pressure, come upright again? Is it or is it not simply due to a little want of consideration of the necessities of the problem and giving too great a weight to the difficulties which everybody must admit have arisen? Armour and artillery are no jokes; they have come as a necessity upon the naval architect; they are weights which have to be carried high up, and the form of the ship must be studied to carry those weights high up. Being a necessity we have to deal with it in that way. It is all very well for the merchant ship-owner to say "I will load a certain quantity of iron or other dead weight placed in a certain position, and I will carefully observe that the conditions under which that ship will behave well at sea shall be carried out faithfully," but the naval architect has that dreadful condition constantly being forced upon him that the weights of armour are increasing, the weights of guns are increasing, they all must be carried above water, and everybody is disposed, far from increasing the weights of engines and boilers, to decrease them as much as possible, while the coal carried will always also be subject to diminution by use. Now the question arises whether the forms of ships which were perfectly good so long as we had only to deal with certain weights, which we could dispose as we pleased, may not be usefully abandoned to a certain extent in view of the present difficulties, and I put it to Mr. Scott Russell as a question whether the only direction of meeting that difficulty is to make a ship so light below and so heavy above that if she goes over to an angle of inclination of 45 deg. in spite of ballast she will turn over and go down. This is a question which interests not merely *dilettanti*, or old officers, it is a question of life and loss of life at sea, a question which affects for all future time the lives of sailors. We want a navigable vessel which will keep the sea in all weathers, and we do not want to be sent to sea in anything, which however beautiful, will probably or possibly encounter weather which will drown the ship and

crew; and we do ask that naval architects shall give us a seaworthy sea-keeping ship, and we suggest to them that there are ways of doing it other than those we have yet adopted of putting all the weights up above, and all the buoyancy below, and then compensating for the position of the weights by putting a little useless weight into the bottom, and so giving us a ship which with a very steady gun platform has yet concealed in her the fearful danger that no one can ever know when he would meet such a wave or wind as would send it to the bottom, and no power on earth and no seamanship on earth could prevent the result. So much is that the case that sailors are forced into advocating the reduction of their sails simply in the feeling that there is no safety in having masts—that you cannot do it. This is a point on which I think the wise, scientific architect may very well step in, and with his comrades reason out the whole state of things. We sailors will be all ready to aid them with everything we can learn at sea, to obey their directions and study what they tell us we ought to study, and I hope the combined knowledge so obtained may bring about a more favourable state of things. Mr. Scott Russell's paper is one of those which lead a great many to think on the subject, and those who are led to think, will no doubt sooner or later take action.

Admiral RYDER: I should like to make a small contribution to this discussion. When I was employed as a naval *attaché* in France, I learned that in every cruising flag ship, there is a member of the Constructive Department of the French Navy, learning from actually seeing at sea how ships behave, his practical lesson of how to design ships. Why that is not done in our service, I have never been able to understand. I am perfectly confident of two things; that the young constructor would welcome most heartily the opportunity of going to sea, and I am perfectly confident the officers on board would welcome him most heartily there. As far as I know, however, at present there is no system by means of which the young constructor can attain any practical knowledge of our ships' behaviour at sea. After the loss of the "Captain," I asked one of the prominent members of the Constructive Department whether when they ascertained by testing that ship that her maximum angle of stability was of such an amount, that did not strike him as being very small, as it did all naval officers. His reply was very simple: "I did not attach importance to it; I have never been to sea; I have never been on a cruise in a ship." There is a very great moral in that remark, and I very much wish that I had any influence with the Admiralty which could induce them to take up the question, sending, as the French do, our young constructors to sea, making their promotion and advancement depend upon their having been to sea, and so learned their profession.

Admiral FISHBOURNE: I may state that that plan was carried out in the School of Naval Architecture established at Portsmouth. The plan had the double effect of teaching the officers on board the mathematical side of the question, and enabling the constructors to learn somewhat of the seafaring side of the question.

Colonel CARTER: Although I am a land-lubber, I take a great interest in this question. Our lecturer has given us to understand that he has a great deal more information to give us, and as this subject is so very important, and ought not to be hurriedly closed, I think it would be a great benefit to the service if, on some future occasion, he will continue his lecture upon this subject. There are some questions I should like to put myself, but I do not feel justified in doing so at this late hour of the evening; I will therefore respectfully suggest that Mr. Scott Russell should be asked to continue his lecture on a subsequent occasion.

Admiral FISHBOURNE: I am sure the Council will be glad to fall in with that suggestion, particularly if Mr. Scott Russell would complete his subject.

The CHAIRMAN: Before asking Mr. Scott Russell to reply to the questions put to him to-night, or to inform us when he will favour us with the completion of his paper—for we must all feel that it is a subject that may well be enlarged upon—I should like to offer a few remarks on the paper, and on some observations that have been made regarding it. I think, with reference to a remark by Admiral Selwyn, we are all opposed to useless ballast, and we may hope that all occasion for it has passed away. It has been, I will not say a custom, but an accident of the past in connection with ironclads, and I do not think you will find anyone connected with the ship-building department of the Admiralty who would advocate putting useless ballast into a ship. I must also

remark that it certainly is not the opinion of naval officers in general that our ships as now built are of such a dangerous form, or weighted in such a dangerous manner, that we should have any fear of going to sea in them in any circumstances whatever. My own opinion of them is, that our ironclads of the present day are, looking to all the services that may be required of them, the finest ships in the world. Admiral Selwyn asked whether it is not possible to build a ship that will right itself when she goes on her beam ends. Many of our ships will do so; I think Mr. White will perhaps bear me out in saying that some of them will go out to more than 100°, and right themselves. I do not mean ironclads, but troopships and others. Many of them would do so if you could insure that their upper works and hatchways were watertight. Our armour-clads and turret-ships would not go over so far with safety but they have such great stability that no sail that they carry, would ever bring them over on their beam ends. If we did not feel safe on that point I do not think any of us would care to go to sea, but I am satisfied I am speaking the opinion of a very large majority of naval officers, when I say that they have no hesitation or doubt in placing confidence in the sea-going qualities, and sea-worthiness of our ironclad ships.

I cannot sit down without expressing my admiration of the clear and lucid manner in which Mr. Scott Russell has explained to us the mystery—wave motion. I do not mean that he has brought forward any new theory, but his exposition has been so clear, that I think anyone who has heard it to-night will remember it as long as he lives. I should like very much to have the period and length of the “standard wave” clearly established, but it is a difficult matter to observe with accuracy, and no one has given the matter more study or conducted more experiments on the subject than Mr. Scott Russell. If officers in the Navy knew what careful instructions are issued by the Admiralty for observations on the length, periods, and height of waves, and on the rolling of ships, and also the admirable way in which it is explained how these observations are to be conducted, I think our naval architects would be overwhelmed with information on the subject, instead of getting it, as they do now, very rarely indeed. With reference to the remark of Admiral Ryder—I clearly understood that when the naval architects were established at Greenwich, it was quite settled that those young men were to go to sea to complete their training after they had passed their examination, and I do think Admiral Ryder’s suggestion ought to be most seriously considered, as it is one of great practical value.

MR. WHITE: Every student of naval architecture who enters the College is under an obligation to go to sea should the Admiralty decide to send him, but no orders on that subject have as yet been issued.

MR. SCOTT RUSSELL: I think I can answer at once the point which Mr. White put, namely, that I had not marked the change of metacentre. I knew that Mr. White would know in a moment when I put these points there (*pointing*) that in the act of doing so, the metacentric height was raised a proportional quantity. And if I had wanted to put the thing technically in shape, as between him and myself, I should have said, “Let us shift this metacentric height, and let us shift the centre of ballast down the corresponding and equivalent quantity, and then we shall by those two means get the two elements of stability, and we shall get them exactly as equivalent of one another, and we shall get exactly the balance I am asking for.”

With regard to ships of war, I am obliged to say that the distribution of the weights of boilers and engines that I have sometimes seen, has been entirely contrary to the principle mentioned, of bringing them as near as possible to the centre of gravity of the ship, and as near as possible to the place where they would act as efficient ballast, and at the same time as weights in the place where they would produce least oscillation. I will not, however, criticise other people’s vessels, because it is not my duty, and I dislike it. I merely mean to say if I had not seen vessels in which all the great weights were utterly erroneously distributed with a view to these points, I should not have thought the observation worth making. I will just give one example. I do not like to mention it because it is a ship of my own building, but I remember having the question to settle, whether I would spread the boilers of a ship out in this manner at a certain distance, or whether I would put two boilers into one, and place them in the centre further down. I took the boilers out of the wings, and put them in the centre and put two boilers back to back; I thus got a good and low disposition of the weights, and made an excellent vessel without

any ballast. The engines and the screw ought to be regarded by the builder as weights, the disposition of which are entirely at the discretion of the designer, and I tell you why: there is no reason in the world why the shaft of a screw propeller should not have any angle you find it convenient to give it, and therefore I say to you in the most decided manner that all the bad dispositions I have seen of screw engines have been made through utter want of judgment and knowledge. You can put your engines wherever you please, which you could not do till we got the screw-propeller.

With regard to waves I have given you experiments occupying a large portion of ten years. My standard wave is based upon hundreds of perfectly exact experiments repeated over and over again, and those experiments which were made between 1834 and 1844 have not, so far as I know, ever been contradicted. I have not in this lecture touched on the subject of the manner in which waves interfere with and modify each other, which makes the observation a matter of extreme difficulty; I beg to say, however, that I shall search the volumes in which I can find any accurate wave experiments, and at our next meeting I shall be most happy to give you a summary of the results of these experiments, and I only hope that they will do what I want, give me my 3-14159 instead of the 3-57 which I am forced to adopt by nature herself pressing it on me.

With regard to what Admiral Selwyn said in regard to the inclinations of a ship, there are forms of ships which no possible derangement could ever turn upside-down; but at the same time I admit frankly that there are ships so constructed that if they were turned upside-down, they would have much greater stability than when they are downside-up, and those are dangerous ships, and ought to be avoided.

The Meeting was then adjourned to Monday, the 9th of June.

Monday, June 9, 1879.

Colonel CARTER: It is with some diffidence that I address an audience upon this subject, but if I have made an error of judgment, I hope you will excuse it. Mr. Scott Russell having evidently from want of time hurried his last lecture to a conclusion, I ventured to suggest from the extreme importance of the subject, which the sad fate of the turret ship the "Captain," had so indelibly impressed on every mind, that he should be invited to address us again. That suggestion was favourably entertained both by the audience and the lecturer, and we have now been favoured with Mr. Scott Russell's further observations, which we must all allow were particularly lucid and clear on that portion of the subject which is both difficult and complicated to discuss. I could not tell, of course, how he would further unfold and explain his subject, so it is consequent upon what I heard at the first lecture and the discussion which followed that I make the following observations. Mr. Scott Russell just had time to draw for us the sectional form he thought best for a stable ship, namely a circle with a pair of shoulders added, which, by adding width, gives stiffness, and showed us the place where ballast should permanently be, namely, at the bottom, but inside the circle, which gives stability. Mr. Scott Russell's idea, so lucidly conveyed, set me thinking, and the problem which had to be solved is what Admiral Selwyn very appropriately mentioned, namely, how can stability be given to ships which are so heavily weighted with massive iron turrets and monster guns on deck, and thick iron sides above watermark? The position that all these things of necessity occupy, renders a ship top heavy, and therefore easily capsized if it is not scientifically counteracted. Without such counteraction it would not require the furious raging of storm ocean waves to effect the capsize; but when a ship has to contend with the violence of fierce winds and rushing mountain waves it should possess all the means available for making her impossible to turn over. Now have our ships every available means to secure this end? I answer No, and in my opinion very far from it. When I first examined the beautiful model of the "Captain" which is in this Institution, I was no longer surprised that that vessel turned over.

My surprise was that she remained so long as she did upon the surface of the sea. And why do I state this? Because—I am afraid I am now going a little at variance with the theory Mr. Scott-Russell has put forward—because she was circular in form below, which offers no resistance whatever to the power of the wind and the wave; she had no keel, which does. I feel convinced that a keel to an iron turreted ship is essential to its safety, and to all ships, I should say, necessary to effect moderation and a lessening in rolling. When a ship with a keel rolls, the displacement of a large body of heavy water which a keel necessitates, would cause the rolling motion of the ship to be gentle and slow, whereby time would be obtained for the mountain wave to pass, and so the ship would roll back again on the opposite side of the wave before she could lurch over to a dangerous angle. To width of beam therefore, which tends, as Mr. Scott Russell has explained, to storm stability, I would also add, as an essential to the ship's safety, a keel. With such monstrously weighted decks as our men-of-war now have, I should not only have a keel, but a keel of a particular construction, that is to say, if such construction should not be found in practice different to what I conceive it probably would be. My theory is that the form of the keel should be such as to make the ship slow in rolling, and this advantage could be secured by making the keel gradually broader towards its base, but tapering towards the rudder as also the stem, so as not to interfere with the proper action of the water on the rudder or retard the ship's onward progress. As the ship rolls, the keel by this form would retard and lessen the momentum of the roll, and so would cause the ship to roll slowly and gently and not violently, which a high conical wave combined with a sudden gust of wind would effect, and with a dangerous momentum, without a keel. There would be an objection to this form if in practice it interferes with the buoyancy of the ship. I do not advocate, however, that the form should be carried to any excess, especially in a very deep keel. If the water below rises equally or nearly so with the water on the surface, the form would not interfere with the buoyancy of the ship; but if otherwise, I think that it would, but probably only slightly, even if the keel were a very deep one. A keel which broadens at its base may require practice to confirm its use, but a keel with perpendicular sides and heavily weighted, I believe to be absolutely essential to safety when ships are weighted on their decks with iron turrets and large guns. Mr. Scott Russell has condemned the "bilge" keels, but I fail to see that they are not a valuable addition to ensure slow rolling. They would, I suppose, cause the ship not to answer her helm so quickly as when without them, but this, if it be the case, is a consideration that is of comparative insignificance to stability, for stability is a quality that our men-of-war must possess over and above every other. I contend that a heavily weighted keel would form the best possible ballast, and would not usurp the room available for storage. I would illustrate this power of securing the greatest stability by bringing to your notice the principle of the steel bar. A steel bar has a long arm and a short arm. I place a weight A at the end of the short arm, and another weight nearly equidistant from the point of suspension C, which I call B, on the long side of the bar. Those weights, we will suppose, balance each other, but when I remove B further towards the extremity of the long arm to D, B will fall, say to the bottom, and A will correspondingly rise, that is to the top, immediately over B. This is exactly what we want our ships to do. Let A now, in its vertical position, represent our turrets and guns, B the keel of the ship, then the further we can have our heavy keel to counterbalance the turrets and guns on deck (which should be, as we can now see, as low as possible) the more effectual is such weight, so that when a ship rolls, which it always must, more or less, when it rides longitudinally over crescent waves, its natural position being at right angles to the surface of the water, B, the weighted keel would, by the law of gravitation, always be forcing the ship to assume a vertical position. A keel, therefore, such as I have indicated, would form the most effectual ballast, and would secure the greatest stability to the ship.

Admiral RYDER: I should like to ask one or two questions. Mr. Scott Russell has given us the length of the wave, the height of the wave, and the period of the wave; but do his researches enable him to give us the angle of the slope of the wave? When we were on the Committee of Designs some years ago, we sought that information, and were told by the scientific gentleman who advised us that the slope

of an ordinary sea wave never exceeded 4 deg., I noticed one of the great waves of translation which he speaks of, at Hakodadi, in Japan. There, everybody was full of an extraordinary wave that had reached them, though they did not know from whence, or anything about it; nor had any living man in his recollection seen a similar wave. It rose eight feet, and they congratulated themselves that it came at low water, instead of at high water spring tides, in which case it would certainly have drowned half the inhabitants. As it was, the top of the wave was only about two or three feet higher than the highest spring, and though it flooded their cellars, I do not believe anybody was drowned. They said there must have been an earthquake on the other side of the Pacific, and so it turned out. I suppose these waves that have their speed due to the depths, when they pass over different depths vary, and acquire a kind of mean speed.

Mr. SCOTT RUSSELL: Always; they go slower and faster.

Admiral SELWYN: I wish to ask Mr. Scott Russell to be good enough to tell us one or two things, and one is whether he has remarked at sea that on the calming down of the heavy sea arising from a gale of wind, the smaller waves gradually merge themselves into larger waves of longer period. Secondly, I would ask whether he considers it absolutely necessary that the bottom should shallow in order to produce the ground swell. I have been a good deal interested in the subject, and am specially interested in what Mr. Scott Russell has said to-night, because, although he gave us the year 1834 as one of the first instances, I have been making researches lately, and I am very much disposed to say that the first record we have of a big wave was in Noah's time, and that there were five deluges recurring after that. In the year 1822, not to go to other instances, the upheaval of the Chilian coast to the extent of eight feet, sent a wave of that character across to New Zealand, and in the submergence of Callão something of the same sort took place. In short, the more we look into the question of such great waves, of such rapid transmission, the more we see that they are principally caused by serious disturbance at the bottom of the ocean. At St. Helena there is a very curious form of wave, which comes in periodically, and in a measure at Ascension also. It is a series of big waves coming in for a day, setting in with awful fury, often in a perfect calm, without any sufficient cause whatever that we can see, and they are perfectly local. They generally set in from the eastward; we do not hear of any great disturbance having occurred, but these rollers set in at periodical times with devastating fury very much of the character of the ground swell of which Mr. Scott Russell has been speaking. I think the paper, both on the former occasion and on this, has very much advanced our mode of thinking of waves in general, and will lead to more close observation among the officers of the Service, as to the formation and courses of waves. As to myself, I am afraid I must still hold to a sort of affection which belonged to my youth with regard to the trochoidal wave in which the friction of the descending particles plays the greatest part in causing the breaker in sea waves. I dare say Mr. Scott Russell, in speaking of the circular movement of an atom of water, will allow that there is always a translation of that atom forwards in every case, combining the circular with the forward movement. With regard to the question of storm stability as distinguished from smooth-water stiffness, Mr. Scott Russell has done a great deal to show us what in his opinion would be the best form of vessel to combat what we all regret, the absence of real stability, although there is a great stiffness of platform in the modern contrivances which they call ships. But I am not satisfied with any of the modes which have yet been proposed for doing away with the difficulty. I see that we are still bound to heavy weights above and light bottoms in order to carry these heavy weights, and as, apparently, the heavy weights must be carried high up, I do not see how by any other contrivance than increasing the weights below, we can balance the weights above; but in doing so, unfortunately for ourselves, we incur the reproach of carrying more weight than we have any use for, and although yachtsmen show an enormous value for what they are pleased to term the "precious metal" in their keels, yet I doubt whether, added to the weights we are obliged to carry, a naval architect would like to be told to carry counterbalancing weights for no other purpose than that of counterbalancing the armour and the guns. Is there any other mode of getting rid of this difficulty? If we are to carry these weights very high up, what advantage does it give us, and why should we continue to do it? It is quite possible the Russians

may be right, and that the time for ironclads is gone, and that there are no more ironclads to be built. But the world does not think so at present, and I am disposed to think the failure of funds has more probably led to that conclusion than any other necessity. However that may be, it is quite clear as long as we have heavy guns and armour, we have to provide for heavy weights on board a floating structure. If we still insist on getting our speed in the floating structure by modern slopes of ten beams to a length, it appears impossible to get rid of the disadvantages of unstable equilibrium. I do not see any way out of it in that direction. If Mr. Scott Russell can give us any idea how we can get storm stability combined with smooth-water stiffness, I am sure we shall be happy to hear it, and I am quite sure if he does not know it he will very candidly say so, and tell us that on our present line there is no chance for our doing much in that direction. He will also, I have no doubt, at some future time, be ready to tell us something about how we can do it, and I hope that time will soon arrive.

Captain BURGESS: I do not know, Mr. Scott Russell, whether you ever saw a form of vessel introduced by Mr. T'ovell, in which all the sections towards bow and stern were semi-circular. He had some vessels built for the Mediterranean trade, and he obtained some excellent results; but I do not think that the plan was ever generally introduced.

MR. SCOTT RUSSELL: One of my first vessels was built in that way.

The CHAIRMAN: I have myself observed several instances of waves such as Mr. Scott Russell described. I was once lying on the coast of Africa in perfectly smooth water with not a breath of air; the glass went down very much, so much that I felt it necessary to get steam up. I walked up and down for hours watching to see what was coming, as the glass continued to go down. Finally I saw a white line on the horizon. This was a solitary wave rolling in about six feet high above the natural level without a hollow in front. My bow was to the wave, I therefore had nothing to do except to steam ahead to keep the strain off the cable. It came along with great velocity. A schooner lay close to us broadside on. Her crew saw the wave coming, they lashed everything on deck, and then got in the rigging. It nearly capsized her; she made a dash at us, took away my quarter boat and stern boat, carrying away her bowsprit and fore topmast. There was only one wave that passed and broke on the beach. I felt sure that a storm had passed outside, and on examining some ships' logs, found that two vessels had been in a circular storm, and one was dismasted. In another case I saw an illustration of the transmutation of small waves after a storm into a ground swell. I was lying at anchor in Table Bay in three fathoms, with 75 fathoms of chain out, in perfectly calm weather; one of these solitary waves came in and took the vessel at such a rate astern as to cause a tremendous jerk as if it was tearing the bits out. I jumped up to see what was the matter but could see nothing. We went forward and the cable seemed to be all right. Concluding that something must have occurred, after supper we hove up and found the anchor shackle had broken. This is why Table Bay is so dangerous to vessels. This class of solitary wave comes and takes a vessel, brings her chain quite straight, and it breaks with the jerk. In another case in China, preceding a cyclone, the whole River Yang-tse-Kiang was unusually red, from the earth being stirred up by the coming storm, quite 48 hours before it arrived. I afterwards traced that cyclone to be 1,000 miles in diameter and to have been 2,000 miles away from us when this disturbance of the water and ground swell came up the Yang-tse-Kiang. Captain Maury's cousin, and other very accurate observers, were in this cyclone; I got their logs and mapped out its course. Mr. Scott Russell has given us a true explanation, and it is most important to recognise the distinction between the first and second order of waves; to confound these is to lose all judgment in the matter. To build ships with reference to one is to have them failing in the other; and to assume that because ships have been safe for a number of years in one class of wave, they will therefore be perfectly safe in another, is extremely unscientific and dangerous. There was some conflict on the last occasion between Mr. White's standard and Mr. Scott Russell's. The question is whether there has not been a confusion of waves as well as of their standards, whether there is not a standard for smooth-water waves and an entirely different standard for storm waves?

Admiral SELWYN: At St. Helena no ship dares to remain at anchor when one of these rollers comes in; if she does, her chains will not hold her, and such a wave with such a velocity of translation meeting a ship which has little initial stability either on quarter, bow or broadside, would be a most dangerous one for her.

Mr. SCOTT RUSSELL—in reply: Admiral Ryder asks me with regard to the slope of the wave. The slope of this wave is an extremely gentle one, but the trochoidal form absolutely remains. The trochoidal form is the result of the combination of the circular motion with the rectilinear motion. The propagation of the wave takes place equal distances in equal times, and the wave being propagated equal distances and in equal times, it is the circular motion that alters the slope of the wave. First of all, the slope of the wave is extremely gentle. I cannot say how small the angle is until it becomes a storm wave, and then the angle certainly gets up to 60° . The storm wave is a sudden elevation of the wave up to double its former height; that always takes place both in the ground swell and in the other. A remarkable thing in the ground swell is this. If you see the ground swell regularly breaking with the waves 20 feet high, you may be quite sure that the water there is a little more than 20 feet deep, and always when this ground swell comes to a height equal to its depth it assumes a position of tottering equilibrium before it gets to the maximum, so that the depth will always be greater than the water appears to be when judged by the height at the top. In like manner with regard to the breaking of the surface wave, apart from all rule of course, the wind will pitch it over and break it, but if you can imagine a surface wave breaking merely by its own gentle curve you will find the storm wave breaks whenever its height becomes equal to about one-fourth of its length. I have never seen one of them able to rise to a greater height than that. The sharpest wave I have ever seen on the surface of the water is a wave of which the height is one-fourth of the length. In regard to the ground swell and the wave of translation the length is very great, but at the same time I have seen them culminating in a smaller height in the act of breaking to that of the ordinary surface storm wave. With regard to Admiral Selwyn's question, I may say I think the ground swell would break by mere accumulation. Supposing an island to rise very slowly, the result will be a very long low wave, and whenever this wave comes into a good deal shallower water the shortening of the wave must increase the height and therefore the long earthquake wave may, by sudden shortening, become a breaker. Tides become breakers; when they come up a shallow river they become bores; although they are very long, still the crest becomes a breaker from, as I think, this shortening of the wave. Supposing a storm to have existed with the surface waves, then the surface waves as long as they continue storm waves, will break, and supposing a second wave of much smaller size goes over the surface wave, it breaks, and therefore I say a great continuation of storm surface waves would break on the top of each other, whenever their crests coincide, and would gradually in that way settle down and be used up.

With regard to the very difficult problem which the Admiral has put to me as to carrying weights high up, without carrying useless weights low down, there is only one solution, and that I think I mentioned formerly. It is to begin with the resolution that we will not carry any useless weights at any cost. Then put as much weight as you think desirable for strength into the bottom of your ship, and so design your engine and boilers that all available and useful weights shall be placed at such a depth as to assist in giving the stability that you want. It really comes to this, that you will keep those top weights of yours as low down as you can, and you really come back to the conclusion that heavy armour high up is unwise, inexpedient, and makes an unseaworthy ship. I advocate keeping the armour low down, not putting tall turrets up into the air, but arming a ship of war with a particular kind of gun kept low down as near the water line as convenient, and in that way making her a good seaworthy ship. I remain of opinion that you ought to consider a ship of war as having this essential point in her, that first she must be a seaworthy ship; and having done that, I think you can make her a perfectly seaworthy ship at the same time that you give her all the protection she wants. What is practice in life but this? Take the inevitable conditions and make the best of them you can. Therefore when a problem of building a ship is given you, and you have given her the right size and shape, and put your weights and your boilers in the right place, and

have kept your guns and armour as low down as you can, you have done all that is possible.

With regard to the question of keel, I would simply say this,—that very often we have no choice. When we build a yacht we are allowed to put the keel as low down as we please, but when we come to build a ship of war, we dare not put an inch of keel on, because of the draught of water. But I will call attention to the fact that the bow of the ship is practically keel and nothing else; it is a sharp wedge and prevents rolling. With regard to the oscillations of a ship, I would also call attention to this, that a ship has no tendency to oscillate. Nothing can cause it to do so, excepting either the wind above, or the action of the sea upon its keels. Therefore it is that I do not like these bilge keels, because they are just the thing which enables the wave to compel the ship to oscillate. The only reason why we do not use keels is, that we must give these enormous ships a limited draught of water. What we must do, is to build the ship of such a form, and put her weights in such a manner that she shall not of herself have any tendency to roll. That is why I begin with the circular form, and with that circular form the ship does not roll. With regard to Mr. White's standard, I think the matter is very simple. In the former lecture I gave this series of waves, and in this series there was a wave which I gave as the standard 3'57. That wave was the result of 10 years' observation, and you find hundreds of those waves in the reports of the British Association, all of them showing this particular dimension as the one standard. Until, therefore, another set of experiments of equal value has been made, establishing some other standard, I think we must keep to that as the old standard. I think that what perhaps misled him was, that he thought I was speaking of the deep-sea waves instead of the surface waves, and if he had been here to-night, I could have presented him with a standard wave, which would be exactly the wave he wanted. There was a wave of 5'67 in this class, and the wave of 3'57 remains to please me in the other class.

Admiral RYDER: Have the experiments been as extensive for that wave as for the other?

Mr. SCOTT RUSSELL: As extensive, and on a much larger scale. The first considerable report was in 1837, and the remainder of the reports were made in 1841.

The CHAIRMAN: I am sure you will allow me to return your thanks to Mr. Scott Russell for his very interesting paper.

NAMES OF MEMBERS who joined the Institution between the 1st July and the 30th September, 1879.

LIFE MEMBERS.

Arbuthnot, William, Lieut.-Colonel 14th Hussars.	Wyndham, C. J., Captain 83rd Regt.
Tyler, Henry E., Lieut. R.E.	McCallum, H. E., Lieut. R.E.
Dunlop, H. D., Captain R.A.	Bruce, E. A., Major Madras Staff Corps.
	Jones, G. Turner, Lieut. R.E.

ANNUAL SUBSCRIBERS.

Markham, Clements R., C.B., F.R.S., late R.N.	Underwood, Walter O., Captain 4th Hussars.
Paget, A. de B. V., Lieut. 68th Regt.	Dick, J. P., Lieut. Duke of Edinburgh's Artillery Militia.
Farren, R. T., C.B., Lieut.-General, Colonel 35th Regiment.	Woolcombe, H. B., Captain R.N.
Carter, F. W., Major Duke of Edinburgh's Artillery Militia.	Whelan, F. A., Lieut. R.M.L.I.
Stokes, Sir John, K.C.B., Colonel R.E.	Carden, Henry C., Lieut. 11th Regiment.
Fordyce, Alex. D., Captain Duke of Edinburgh's Artillery Militia.	Thompson, Ross, Lieut. 11th Regiment.
	Yarde-Buller, Hon. Walter, Lieut. 11th Regiment.