ON ARMOUR-PLATED SHIPS, AND THE STABILITY OF VESSELS IN A SEAWAY, CONSIDERED IN RELATION TO THE PRINCIPLE OF THE LEVER AND THE LAWS OF MOTION.

By MR. BARRASS.

MR. CHAIRMAN AND GENTLEMEN,

It is proposed to discuss the question of the behaviour of vessels in a seaway, and to consider that behaviour in relation to the principle of the lever and the laws of motion, and by a process of consideration based upon the conditions which actually obtain when the vessel is at sea, to endeavour to arrive at more satisfactory results than those obtained by the geometrical methods which are in present use.

When a vessel has left the dock or the quiet river (the condition under which she has been treated by her architect) and has proceeded to sea, she has entered a new life, from the passive piece of gravitation in the dock she has become, as it were, a thing of life and action, —a body in motion, and as a body in motion will, no doubt, obey those principles of mechanics, and be governed by those laws of motion which rule universal matter, as may be observed if we but search for the causes in logical sequence of investigation, from the effects as they are presented to us.

From the nature of this proposition it will be desirable to state briefly the theory which prevails at present, and for what reason exception is taken to it. To pass in review the most prominent features of those labours which have recently extended the view of the subject, and then to explain how it is proposed to account for the behaviour of vessels in a seaway by the principle of the lever and the laws of motion, and by tracing the causes of rolling, and thereby the relation which is subsisting between the cause and the effect, that it may be seen more clearly how to ensure as far as practicable a steady gun platform—a vessel that shall roll as little as possible, both in extent of angle and number of times; for now that iron will, no doubt, take the place of wood in the construction of the Royal Navy, with heavy armour plates on the sides, tending to make the vessel roll through a greater angle, it becomes a desideratum to determine the first principles involved in the cause, that control the motions of a vessel in a seaway, that we may know how to deal with the subject, and be enabled to press into our service the full benefits which armour-plating may afford.

Before proceeding, however, with this inquiry, I wish to make a few observations on the story of the backings, and the iron *versus* wood question; for it appears to me that, captivated by the term cushion, wood backing threatens to run us into a rut, whence it may take a half-century of talk, and then only, perhaps, on the occasion of some national calamity, to drag us out, while no efforts should be relaxed in

Fig. 3.
Diagram showing the present Geometrical
Method of considering the stability
of Ships.

Fig. 2.
Orbits of Centre of Buoyancy
of
Rising Floor Ship.

Fig. 1.

Diagram, showing Iron Bucking
stopping the Shot when half its
force has been delivered.

Turning to the iron *versus* wood question : it is said the "Prince Consort" has suffered no damage from her unlucky advent in the Channel. Having arrived in quiet water again, and the straining action having ceased, the joints closed up again, and the leakage stopped; it is made out that she shipped all the water. If a wooden built ship in herself creaks, twists, and opens her joints in a seaway, what will she be likely to do with 600 or 1,000 tons of armour plates hanging upon her sides. Consider for a moment the heaviest masses we have in motion on land, a fly wheel of a rolling mill, or a beam of a pumping engine, weighing from 20 to 30 tons only, and see the proportions and continuity of strength, that must be preserved in every detail of construction that the integrity of the structure shall not be vitiated by a weak point, and then turn to these wooden vessels, armour-plated, and reflect upon them in a sea-way, not put in motion like the almost uniform motions of machinery, but pitched about first one way and then the other, with a mass of iron of the weight of one of the Britannia tubes hanging upon their sides; and consider the details of construction which the ship carpenter has to depend upon to keep the structure together; for example, the coaks at the butt joints of the futtocks, which merely keep them in place, but give no cohesion and no transverse strength, the attachment of the beams to the sides, the knees, fastenings, and riders, fixed with spikes or bolts, which however strong in themselves, only serve to strengthen the ship by the bearing area, which the wood offers to the bolt—a soft material pressing against a hard one—the bolt pulling for itself an oblong hole in the timber long before either the bolt or the timber which it is fixing has received one tithe of its working strain. Putting these things together, and conceiving the strains that must be thrown through the beams and sides of an armour-plated wooden-built ship to pull her out of shape at every roll in a sea-way, it certainly appears unreasonable to expect that they can preserve their form and efficiency for any length of time under such circumstances, while it is clear, that if the Royal Navy is to march with the times, to press into its service the resources of modern industry and modern improvements, and is to meet modern necessities, it must be built wholly of iron or steel, but applied in such a manner as to meet its special requirements, and when that is done, I will venture to affirm that there is no property you can fairly claim for a wooden vessel, that cannot be reproduced in an iron one, with a fourfold higher ratio of efficiency.

With respect to the fouling of iron bottoms, there is in this Institution a model of an invention which seems quite adequate to remove that difficulty: viz., to fix thin planks over the bottom, and copper the planks; the planks could be well bedded in marine glue or stiff red lead paint, and secured with coach screws from the inside.

Proceeding to Stability in a Sea-way.—The theory which obtains at present for determining the stability of ships was introduced by Bougour, in 1746, as a measure of the stability of *floating* bodies, and is illustrated in its application to ships by a geometrical figure, in which the ship is supposed to be heeled over a very small amount, by drawing a new water line at a small angle with the first horizontal one,

and thus exhibiting, that in heeling over there would be a triangular prism emersed and a similar one immersed (Fig. 3). These prisms were taken as right lined figures, and the centres of gravity therefore of each triangle, at one-third of its height from the base or extreme breadth line. And from a righting moment based upon the transfer of these solids of emersion and immersion on supposed rolling, another righting moment was determined by drawing a line parallel to the inclined water line from the centre of buoyancy, and setting off on that line a distance which, when multiplied into the total displacement, gives an equivalent righting moment to that of the triangular prisms near the water line, and from this new centre of displacement ($a a a$), a perpendicular is erected at right angles to the inclined water line, and where it intersects the middle line of the ship, this point is called the meta-centre (Fig. 3, $b b b$), and its height above the centre of displacement, is the measure of the stability of vessels used in France, and on the continent generally.

This method of estimating the stability of vessels is liable, in its application, to grave errors. Ships may have a widely different form—may have a deep or a shallow section, or have a rising floor, and the stabilities of each be as wide as the poles asunder, and yet their stabilities estimated in this manner would be much about the same, seeing that at the small angle at which the heeling over is calculated, ships, at and about the water line, differ inappreciably (Fig 3).

Atwood, however, showed clearly enough in the Philosophical Transactions for 1796-1798, that the effort of a vessel to return to her upright position was due to the centre of displacement of the whole geometrical form of immersion after inclination, and the result of Atwood's theorem is multiplying the displacement or weight of the vessel into the horizontal distance between verticals falling through the centres of gravity and of displacement for the righting moment (Plate XVI. Fig 4). Atwood calculated the centre of displacement for several vessels at an angle of 7° , a process and mode of treatment he has since been so much followed in by English naval architects, as to justify its being entitled our system, though it still retains the geometry and nomenclature of the meta-centre, and the height of the meta-centre above the centre of gravity is considered the measure of stability.

There are many interesting points in the geometry with which this subject has been associated, which there is not time to introduce here, but these two statements may be taken as representing the theory of the stability of vessels as held by naval architects.

As applied to the stability of *floating* bodies in still water, the theory is satisfactory enough, but a vessel in a seaway is not a floating body only depending upon her flotation, as she was in the dock, or as she was represented on the sheet of drawing-paper by her architect; and it is in the application of this theory of floating bodies in still water, to vessels in a seaway, to which exception is taken, as not touching the conditions under which the vessel is then placed; indeed, so far from there being a true analogy between the conditions under which the theory is applied and the conditions under which a vessel is situated in a seaway,

Fig. 4.

Fig. 5.

Fig. 6.

they are absolutely reversed. Instead of the vessel being put in motion, or heeled over by an external force, with the water at rest and resisting the motion, the water is in motion and puts the vessel in motion, and that unceresness in a seaway is not only the penalty of great statial stability, as Sir William Symonds has put it, but the penalty also of a false logic, a logic which accepts the property of the water when it is still, but ignores the same property when it is in motion, for the stability on paper or in quiescent water is derived from those very proportions which conduce to instability or excess of motion in a seaway.

Passing now to the paper on dynamical stability by Canon Moseley, in the Philosophical Transactions for 1850, the author proposed to consider the amount of work which would require to be done upon a vessel to heel her over.

If a force be applied, say to the masthead, to heel a vessel over, the force, or the mean pressure (for it will be a variable one), multiplied into the space through which the force has passed, the product will be the work done, the dynamical effect required to heel the vessel over that amount, and such as might be done by the blow of a wave, or a gust of wind; and it was proposed to measure this work by the product of the weight, and the sum of the spaces through which the centre of gravity was raised, and the centre of buoyancy lowered, the author observing that the subject had hitherto been viewed only in the point of view as to whether any given position be one of stable, unstable, or indifferent equilibrium, or that which determines what pressure is necessary to retain the body at any given inclination.

Experiments were made at Portsmouth to test the reliability of the formula based upon these considerations. In those with the triangular model the differences between the dynamical stability as calculated from the formula, and those determined by experiment, are given in the following table:—

Angle at which the model finally rested in statial equilibrium.	Angle through which the falling weight deflected the model.	Differences between the calculated and experimental results.	Leverage between the centres of buoyancy and gravity.
8°	15½°	1.29 per cent.	0.615
12½°	23½°	3.73 „	
13	24	19.16 „	
13	25	31.34 „	1.149

which shows that when the model was deflected through 15½°, the difference was only 1.29 per cent., but increased in a much greater ratio than the increase of angle of deflection, the difference between

23½° and 25° being 28 per cent., and indicating that at about 2 more degrees of deflection the difference would be about 100 per cent., and that there must be absent from the formula some fundamental element in the inquiry.

The formula takes no cognizance of the lever by which the work is done in this case. The lever is the horizontal distance between verticals falling through the centres of gravity and of buoyancy. It is clear that a vessel might have double the beam, and require double the amount of work to be done upon her to heel her over with the same amount of rise or fall of the centres of gravity and of buoyancy, while the formula for dynamical stability would make both alike; or it may be put in another light, a form of displacement might be worked out in which the whole of the work done would be expended in constituting the aqueous lever which is forming itself to resist the heeling over, with a centre of buoyancy neither rising nor falling, and perhaps with a centre of gravity falling and assisting it. Dynamical stability in still water, however, being governed by exactly those conditions which govern the statical, the one will always be in the same ratio as the other in different ships, and Canon Moseley's formula may be said to leave the subject just where it was, but under another name.

The learned author also entered into an elaborate mathematical investigation as to the time of rolling or periodic time, in which the ship is considered as an oscillating body, and its behaviour in a seaway is sought to be accounted for on the principle of the pendulum.

These considerations, however, appear to be based upon an erroneous analogy, though not so erroneous as that of Chapman, who considered the vessel as a pendulum, whose point of oscillation is the meta-centre, and centre of oscillation the centre of gravity. I believe that a little further reflection will show that the question does not belong to the department of central forces at all; indeed, I do not see how it can possibly belong to it, for a vessel in a seaway cannot be said to have any centre or axis of revolution or oscillation. It is true the centre of gravity is endeavouring to roll round the centre of buoyancy, but it is always slipping away into another position, both laterally and vertically, the radius of gyration ever varying; and to endeavour to account for the behaviour of vessels in a seaway upon such an hypothesis, seems to me to be quite hopeless, and as Dr. Woolley has truly observed in his able opening address at the Institution of Naval Architects, "the mathematical expressions for the time of rolling afford very little clue to the behaviour of a vessel. Ships in which this element is nearly, if not quite, the same according to calculation, are as wide as the poles asunder in their actual performance at sea, so that while one in a heavy sea rolls with considerable ease, another is so uneasy as seriously to endanger her masts, and in order to bring the case within the grasp of mathematical analysis, so many assumptions and limitations are necessarily introduced as to ignore the form of the vessel altogether, except just about the water line. I believe," continues Dr. Woolley, "the calculated time for the 'Vanguard' and 'Canopus' differ very slightly." You know their relative behaviour. Their solids of immersion at an angle of 7° are as

5 to 1 with a breadth of 57·6 feet in the "Vanguard," and of 51·8 feet in the "Canopus," when heeled over, and with this greater breadth and solid of immersion (and, therefore, the probability of the whole geometrical form of immersion partaking of that character, and giving a greater lateral traverse to the centre of buoyancy) we seem to have indicated to us why the "Canopus"* rolled slowly and easily, while the "Vanguard" rolled very much more quickly and uneasily, and why those very properties which give great statical and dynamical stability in quiet water, upset all calculations as to periodic time, and produce a reverse result as to stability when the vessel becomes a body in motion actuated by the waves.

It will be desirable now to review briefly those hypotheses which have been appended recently to this subject, namely, the supposed motions of the fluid particles in waves, and the supposed configuration of the waves to some mathematical curve, and the supposed periodic time of transit.

With respect to the motions of the fluid particles in waves. If we think upon the transmission of force as illustrated by the old experiment with elastic balls, and bear in mind the mechanical property of water of being competent to pass a great force through its particles, and combine these with a consideration of its being under the influence of the law of gravity in the vertical direction, then the whole phenomena of wave motion is easily explained. Wave motion is the motion of a force only passing through the particles. The wind blowing in a horizontal direction communicates its force to the fluid particles, but by their close contact and resistance to receive motion in that direction are driven up, the horizontal force exceeds the gravitating force, until they have been driven up high enough to balance it and pass it on, and so giving direction to the wave force. The direction in a gale being that of the wind, in a calm that of the beach,—the horizontal line of least resistance to its transmission; but in a cross and troubled sea, or behind piers and breakwaters the forces meeting, dividing and playing through the particles in sudden and ever varying movement, sometimes two great forces meeting, and the resultant producing a much higher wave than usual, and with the fall of the wave all trace of it has vanished from the spot; where we saw the huge wave we now see comparatively smooth water, for with the fall of the wave, the vertical force which was the resultant of the forces meeting, is again divided up and sent into other places to repeat the operation, and that which has sometimes been considered an optical illusion, becomes, when accounted for, a solemn and instructive fact.

The solitary wave traversing the ocean, is a force which has received its direction and amount at a distance from the place in which it is met, it passes through and leaves the particles in the same horizontal position in which it found them, and without having impressed its hori-

* Captain Fishbourne, R.N., who revised this paper for Mr. Barrass, after his departure from England, states that "'Vanguard' rolled both *deeper* and *faster* in a seaway than 'Canopus.' The mistaken views arose from overlooking the differences of the amount of vis viva, arising from the two forms: this vitiates all calculations."

—Ed.

zontal motion upon them; and if the wave be so high that the ship breaks the contact of the particles, then, like the last ball in the experiment mentioned, the last particles take up the motion of the force and momentum, and a blow is the result.

The motion of fluid particles, then, in wave movement, is simply an up and down one (as sailors have long considered it to be), but having a tendency to slide down the side of the wave, according to the resultant of gravity and fluid pressure, and the time there may be to bring these forces into action.

The behaviour of the vessel, therefore, cannot be influenced by the behaviour of the fluid particles in wave motion, because they are governed by the same laws and conditions as the vessel herself, she riding freely up and down and over the wave, but having a tendency to slide down the side of a wave in the direction of the resultant of gravity and fluid pressure. Captain Fishbourne informed me that this tendency was most distinctly felt on board rising floor ships, jerking bodily down when on the side of a wave. An inspection of the diagram will explain it as being due to the parallelism of the floor of this class of vessel, with the surface of the wave when on the side of it.

How far the wave forces may pass on so uniformly, both in amount of force and period of time, as to present the repeated configuration of a geometrical curve, and to what extent any theoretical conclusions could be based upon such considerations, your own practical experience will have informed you.

The proposition of Mr. Froude, however, calls for a more detailed review.

The author, on the strength of some experiments with a floating plumb bob, proceeds into a laborious and elaborate mathematical investigation, which results in proposing what appears to be more a question of mere ballasting than a question of the science of naval architecture, viz., to manage and control the behaviour of vessels in a seaway, more by the disposition of ballast than by the form of the ship, stating that he is satisfied if you take two ships differing as widely in their forms as those of the "Albion" and "St. Vincent," and load them so that they have the same periodic time in still water, they will perform almost identically when rolling in a seaway, and that all ships having the same periodic time or period of natural roll when artificially put in motion in still water, will go through the same series of movements when subjected to the same series of waves, whether their stability in still water be due to breadth of beam, or to deeply stowed ballast.

The experiment with the floating plumb-bob (Fig. 6), and which the author considered as exhibiting his fundamental law which governs the motion of a ship on waves, was made with a small cork-float about four inches diameter, like a life-buoy with a mast fixed obliquely in one side of it, with its apex perpendicular over the centre of the float, and having a small plumb-bob suspended from it; and because the plumb-bob remained central to the float when it was disturbed by waves, the author proceeded to consider the conditions of a floating

body to be the same as surface fluid particles, and to assign them to specified dynamical conditions which the position was supposed to impose upon them.

It will be observed that a float with a loaded mast fixed in one side of it becomes in disturbed water a variable lever of the second order with respect to the fluid pressure to move it, on the transit of a wave; the power of the wave water to move it, being directly as its pressure when under the mast, but as the wave passes on under the float, the leverage of the fluid pressure to move it, is increasing, until when the mean pressure of the wave has arrived at the opposite side of the float to that in which the mast is fixed, the leverage of the water to move the loaded float is increased 100 per cent. to move it quicker or in half the time at this period of the wave transit, than when it was underneath the mast, so that the cause of the plumb-bob remaining central to the float in disturbed water is a mechanical one, and the mast has a tendency to make two complete vibrations for one wave transit, and when the flexibility of the cork and mast are considered, the variability of the leverage of the disturbed water, and it not having a rigid fulcrum to work upon, it is not to be wondered at, that the masthead flew about, and did not give the plumb-bob time to do otherwise than to remain central to the float.

I am far from wishing to depreciate Mr. Froude's labours; indeed, I am ready to acknowledge having been much instructed by them; but from the premises to the conclusion and throughout all their argument, they appear to me to be either illogical or in absolute error. They start upon an experiment which I have shown to have been misinterpreted, and are continued upon assumptions which are only permissible because they are not absolutely impossible, whilst strangely enough, they end in but one practicable measure, that of favouring a maximum beam; so that, taking the author's conclusions on his own terms, he ends as he began, with recommending that very condition which was known to give great statical stability in quiet water, and the instability in a seaway of the sailor. As to the idea that a steady vessel can be made out of a bad form, or that the form is immaterial, and that in the case of an armour-plated ship (with the heavy armour plates on the extreme width and the engines and boilers nearly on the extreme bottom) the effects of these weights on the motions of the vessel can be modified or neutralised in a bad form of vessel by a few tons of ballast placed wherever you like, I must confess that, to my mind, the proposition seems an absolute delusion.

I now proceed to explain how to account for the behaviour of a vessel in a seaway on the principle of the lever and the laws of motion.

When a vessel is rolling in a seaway, a lever is formed on each side from the resultant upward pressure of the fluid, the centre of buoyancy has acquired a position in this rolling over which gives it a command—a leverage to move the vessel, and to cause the motion of rolling in disturbed water. That is to say, though there is not a rigid fulcrum, in the usual significance of the term, but the upward pressure of the particles are alternately becoming the power applied, and the

fulcrum, as the one exceeds the other on the rolling of the vessel from side to side; and the distance, therefore, which the centre of buoyancy traverses from side to side on rolling will be a leverage (Fig. 7, 8, 9, Plate XVII) presented to disturbed water to put the vessel in motion.

In no department of the inquiries which come before this Institution have the labours of Captain Fishbourne been more fruitful of useful results than in this upon which I have the honour to address you, and from him I have to acknowledge receiving valuable practical assistance and counsel in the preparation of this paper. It was to his published lectures on naval architecture in 1846, that I owe the knowledge of the views of the "Naval Architect" not meeting the requirements of the fighting sailor, and the inducement to look into the matter.

I was not aware, however, that Captain Fishbourne in subsequent papers had introduced such a mode of viewing the subject as referring the influence of the passing wave on the vessel to the principle of the lever, or I should have left the subject in his hands; but having embarked in it, I will state the results. My conclusions, it may be observed, were drawn from small experiments and a process of reasoning. Captain Fishbourne's conclusions are based upon practical experience at sea, and demonstrated by the facts and figures given in the following table of recorded results of the actual performances of vessels of the Royal Navy, and which prove beyond doubt and without exception of example, if even it could not be proved logically and mechanically, that a beam relatively great to the depth of displacement, is that very condition which goes far towards making a rolling ship in a seaway.

Table showing the relation between the beams of vessels and their behaviours in a seaway :—

Name of Vessel.	Half breadth.	Depth.	Difference.	Angle rolled through.	No. of times per minute.
Albion.	30' 0"	24' 4"	5' 8"	49°	13
Rodney.	27' 0"	21' 8"	2' 4"	27°	8
Queen.	30' 0"	25' 3"	4' 8"	20°	7
St. Vincent.	26' 9"	25' 3"	1' 6"	13°	5
Trafalgar.	27' 6"	25' 3"	2' 2"		1
Superb.	28' 6"	24' 7"	3' 11"		3
Canopus.	25' 6"	23' 10"	1' 9"		2
Hecate.				10°	8
Antelope.				5°	4

Diagram showing the Rise and Fall and the Leverage of the Centre of Buoyancy in a Seaway of
Rising Floor Ship
Rolling 30°

Fig. 7.

Flat Floor Ship
Rolling 30°

Fig. 8.

Warrior
Rolling 15°

Fig. 9.

Diagrams showing

The Fall of the Centre
of Buoyancy on Rolling of
Rising Floor Ship

Fig. 10.

The Rise of the Centre
of Buoyancy on Rolling of
Flat Floor Ship

Fig. 11.

If anything more were wanted to prove the truth of the argument, it is supplied in the fact of a vessel rolling more when light than when laden, for it must not be supposed that the water "per se" has a greater power of flotation then. The mind must not admit the idea that because the vessel is lightened, the water will necessarily have more command over her without a mechanical cause other than its buoyancy, for just in proportion as the vessel has been lightened, so has the floating power been reduced also; and if a vessel when lightly laden is rolled about by a sea more than when it is heavily laden, it must be due to the floating power having then a greater proportionate command over her, a greater leverage with a lesser weight to put her in motion when light than when laden.

Now, if we apply the present theory to the same vessel when light and when laden, we find that though the centre of gravity has been raised by her being lightened, the meta-centre has been raised also, so that virtually the theory would give the vessel the same stability, when it is so well known that the contrary is the result in disturbed water, and the mechanical cause of it seems clear enough. If a vessel has been lightened on her voyage by a foot of her draught, the mechanical power of the waves to put her in motion would be the same as if her draught had been preserved, and two feet had been added to her beam. If she were lightened by two feet of her draught, the mechanical equivalent would be as if four feet had been added to the beam; and if she now draws three feet of water less than when she started, the waves will have the effect to put her in motion as if six feet had been added to her beam.

The simple fact appears to be this: that the course of naval architects has been, is, and I fear will be, until they are shamed out of it, to consider the water and vessel at rest only, allowing, as it were, the water to have the power to float the vessel when at rest, but ignoring the power of the water to put the vessel in motion if it be disturbed, forgetting that the conditions are reversed in passing from quiet to disturbed water, and that what was the lever in the first case to resist the heeling over, becomes in the second the lever to put her in motion.

Let me be understood as taking no part with those who consider that a large amount of ignorance prevails amongst the professors of this science, knowing that the highest attainments are requisite for its pursuit, and remembering the channels which a long current of thought and treatment tend to deepen and render difficult of being diverted afterwards.

But it does appear that they committed an oversight in letting their theory get into such a rut, while they have been somewhat unwilling for any one to help them out of it. Now, they might be very well sure that if their theory was worth anything, and rested upon a foundation which they relied upon themselves, and could communicate to others, and be relied upon by sailors, their views would not be questioned, and my appearance here would be inexcusable. But what do we find? One professor for a flat floor, another for a rising floor, one for a barrel bottom, and another for a cigar shape altogether, while one would always have a clipper section totally irrespective of first con-

siderations; and whether the vessel was simply to sail fast or to carry a broadside armament, one for a full fore body, and another for a full after body. The former not having a reason of his own, goes to nature for one, and cod's heads and mackerel tails become the standard for the forms of ships, and not unfrequently a small model dressed down here, and shaved down there, until it pleases the eye, is the theory employed. Is it to be wondered at then, seeing these things, that this subject engages the attention of inquiring minds, whether they may belong to the profession or not?

But the fishy analogy is somewhat amusing, inasmuch as a fish wags its after body and tail to propel itself quickly, and if any analogy subsisted in the view, the ship should wag her after body and tail also, but as the ship does not do that, the forms of fish are no clue as to what ought to be the forms of ships. If we endeavour to interpret nature on first principles, it may be that since a fish propels itself by a muscular exertion from the shoulders to the tail, and its power, therefore, to work the after body being inversely as its length and directly as its depth and breadth, nature tends to produce that muscular development which enables the fish to fulfil its functions on mechanical principles, and it is supplied with a good leverage and quantity of muscle where it is wanted—at the shoulders.

I have now to propose the consideration of a vessel in a sea-way as a body in motion, and as a body in motion subject to those laws of motion which are governing all matter in motion.

When a vessel is rolling in a seaway, the centre of buoyancy in passing from side to side, may rise or fall in doing so, and the centre of buoyancy being the centre of support, if the centre of support falls on rolling, then the accelerating force of gravity will come into action, tending to continue the rolling (Figs. 10, 11). Thus the centre of gravity of the vessel is rolling through an arc, and the versed sine of that arc may be taken as the measure of the accelerating force of gravity to continue the rolling; but if the vessel in rolling, has, as it were, lost her point of support, then the vessel is permitted to continue the rolling, and the amount of the accelerating force of the gravity of the vessel to continue the rolling, may be measured by the versed sine of the arc of the centre of gravity, plus the versed sine of the arc of the centre of buoyancy; and thus if the centre of buoyancy falls, it permits the vessel to roll through a larger angle than it would do, if the centre of buoyancy rose with the rolling, and presented a retarding force to the motion.

I am doubtful whether I may have succeeded in conveying the proposition to your minds; the subject is a subtle and difficult one, and I have not yet been able to devise a moving diagram to illustrate it, which it would require to do, to demonstrate it clearly; but I think if you will conceive, that if a vessel's geometrical form of displacement is such, that in the act of rolling, the water surrounding her has by the action of gravity given out a force—a resultant fluid pressure at a greater height, produced a dynamical effect, a force moved up through a given height, and that the effect upon the vessel is the same as if an hydraulic press had been acting on each side of the vessel at each

roll, and thrusting out its ram with a pressure equal to the weight of the vessel, and through a space equal to the rise which may be given to and at the centre of buoyancy, then you will form some conception of the enormous power which a vessel may extract from the subtle element in which she is rolling, if you but give her a geometrical form which will enable her to do so, and make her a steady vessel.

Thus, suppose the displacement of the "Warrior" to be 10,000 tons, that she is rolling ten times a minute, and that if by flattening the floor, the centre of buoyancy was made to rise six inches higher than it does, or not to fall so much by that amount; then multiplying these together, and by 2240, the number of pounds in a ton, we have the dynamical effect of 224,000,000 lbs., raised one foot high per minute, and dividing by 33,000, we have a power equal to that of 6,787 horses, that would be given out by the gravitating force of the adjacent water, to keep her a steadier vessel, if her geometrical form of immersion were such, that in the act of rolling, the resultant fluid pressure, the centre of buoyancy, rose up against the roll six inches more than it does.

Referring to the diagrams (Figs. 7, 8, 9) in illustration of the point, they show a rising floor vessel, a flat floor vessel, and the "Warrior," one-sixteenth the full size, all of the same beam and draught. In the rising floor vessel, the centre of buoyancy falls $8\frac{1}{2}$ inches through 30° of roll, when it suddenly commences to rise, as shown by the orbits of the centre of buoyancy in the diagram (A A Fig. 2): This indicates that vessels of this form will be easily set in motion, roll through a large angle, and quickly, but will be suddenly arrested near the termination of each roll, checked with a jerk, as it were, enough to throw the masts overboard, and then as quickly sent back again, for just as the centre of buoyancy has commenced to be effective to control the rolling, it has then acquired a great leverage to return the roll quickly.

A phenomenon of frequent occurrence also bears upon the point. When quick-going steamers are passing over shallows, waves are raised at the bow and stern by the pressure from amidships, the vessel then loses a portion of her displacement amidships, but gains it forward and aft by these waves which are raised there, and in proportion as the buoyancy has been increased forward and aft, and lost amidships, the vessel has been made temporarily of a peg-top form, from losing the displacement where the floor is flatter, the centre of buoyancy falls on rolling, and, therefore, she rolls easily.

The incident related by Sir Heron Maxwell also might be mentioned, that when the "St. Vincent" was perfectly steady, the "Albion" was lurching over in a quiet sea in the Bay of Biscay, and shipping 100 tons of water through her lower ports, to the affright of the Admiral Commanding.

The new armour-plated frigate, the "Valiant," judging from her section, will be a second "Albion," though perhaps not quite so bad.

In the flat floor vessel, the centre of buoyancy rises $9\frac{1}{2}$ inches through 30° of roll and still continues to rise, as shown by the diagram (B B Fig. 2). This indicates that vessels of this form will always be

steady, roll through a small angle, and slowly as well, because the centre of buoyancy is always exercising a retarding force to the roll of the vessel, while the form of displacement develops only a small lever to induce motion in disturbed water.

Naval architects will tell you that this will make a most unsteady ship, from the bodily rise and fall of the centre of gravity which the rise and fall of the centre of buoyancy may give, or which the form of immersion after heeling over may give. An argument which not only appears incorrect, but it is the veriest rubbish, as if the bodily rise and fall of the centre of gravity as exhibited by their geometrical figure in still water can be compared to its being thrown and pitched about in a seaway ten times as many feet as the drawing will exhibit inches. Besides the centre of gravity is an abstraction, while some of its items might be so situated in the ship as to take away all grounds for this argument. The stability of a nearly complete homogenous cylinder wholly depends upon the bodily rise and fall of the centre of gravity.

Taking even a common sense view of the matter, apart from theoretical grounds, does it not appear reasonable to expect a vessel with a flat floor to be steady in a seaway, seeing that, on her rolling, a large nearly flat surface is pressed downwards at a maximum depth, and therefore exercising a maximum effect to resist the motion; while in a circular or peg-top form, that resistance to the motion is lost in proportion to the vessel partaking of those forms, when instead of a nearly vertical pressure at a great depth, it becomes more of a side pressure at a lesser depth, and for both reasons not so calculated to resist motion in a seaway as a flat-floored vessel.

In ships of an intermediate form, their behaviour in a seaway will be of an interesting nature. The centre of buoyancy of the "Warrior" neither rises nor falls within a roll of 15° (C C Fig. 2). This indicates that vessels of the "Warrior," "Canopus," and all those forms approaching to or possessing the barrel bottom, will roll through a lesser angle than the peg-top class, but through a greater angle than the flat-floor class, their motions will be much easier than the former, but not easier than the latter.

Recapitulating, in conclusion, the results which flow from these considerations:

1stly. The present method of treating the stability of a vessel as that of a floating body in still water, is illogical and does not touch the question of the stability of a vessel in a seaway, inasmuch as in still water it is the water which is resisting the heeling over on the application of an external force, while, when the vessel gets into a seaway, the conditions are reversed, the water is then in motion and is putting the vessel in motion, without the presence of and without any reference to the force by which the heeling over was effected in still water, and therefore that form of body which would offer the greatest stability in quiet water, will present it to put the vessel in motion when she has passed into disturbed water.

2ndly. The centres of gravity and buoyancy ever moving about with every varying condition of loading, trimming, pitching, rising up

and falling down, and rolling in a seaway, the problem can scarcely be considered as belonging to the department of central forces, and therefore any investigations based upon the principle of the pendulum cannot but be questionable, if not erroneous; while if we consider upon what actually does take place of the centre of buoyancy forming a lever of the second order of which it is the power, the centre of gravity, the weight, and the fluid pressure on the other side the fulcrum, and that all these are in motion and with a centre of buoyancy, either rising or falling, either using or losing the power which it may command. It would appear that the principle of the lever and the laws of motion are logically applicable to the case, and though it will still be beyond the grasp of mathematical analysis, at least so far as to determine absolute quantities, they are sufficient to account for the behaviour of vessels in a seaway.

3dly. That for fighting ships where accuracy of fire is necessary, and therefore a steady gun platform, the floors should be flattened first, and then reduce the beam as much as is practicable.

I now submit to your judgment how far these observations coincide with your practical experience on board ship at sea, and how far you may consider the course indicated to be calculated to ensure you the full benefits which armour-plating may afford, and that its utility shall not be nullified by a bad form of vessel, and if, in making these observations, I have at any time spoken with more assurance than my experience and these circumstances would warrant, I trust you will attribute it to the instinct to clothe the language of a firm conviction in the language of earnestness upon a serious and important subject, rather than to forgetting the assembly which I have had the honour to address.

MR. MICHAEL SCOTT, C.E.: To my mind this is a subject of such intense difficulty that one cannot speak upon it without some consideration. If the discussion were to be adjourned I might perhaps be prepared to make some observations upon the subject. The paper has been to me very interesting, but it is quite obvious from its very nature that it is difficult to follow the argument, or to criticise any of the statements made in it, without some time for consideration. However, there are one or two points that I might notice. One is with respect to the form of the fish as distinguished from the form of a vessel. The fish is a wholly immersed body; the ship is only partially immersed. I quite agree with the author, so far as I understood the paper, that it is possible to draw very erroneous conclusions from the form of a body wholly immersed, such as that of a fish, if it be intended to apply it to a vessel which is floating on the surface. Another point that struck me was, with respect to the motion of water in a wave. We recognise waves of different characters. In one wave, the motion is what the author has described, very much to leave the particles in the same horizontal position that they were in before disturbance. In another form of wave it is not so; the water is absolutely in motion, and it exerts very considerable power on any body that is floating on its surface at the moment. I do not know that I quite understood the author's criticism on Mr. Froude's theory. I

heard Mr. Froude give an explanation of that theory, and it appeared to me to be very satisfactory. But it is confessedly a subject of such difficulty, that there is room for a wide divergence of opinion; and I think more might be learned from the practical experience of naval officers, with respect to vessels of various forms, that would be more interesting to this Institution than anything I could say upon the abstract question of theory.

Captain E. G. FISHBOURNE, R.N., C.B.: I suppose I ought to make some remarks, as I have been alluded to, and more especially as the last gentleman who spoke seems rather disposed to affirm the correctness of the views of Mr. Froude. The tables on the wall are founded upon actual experiments, I would rather say upon observations than experiments. ["Table showing the influence of beam upon the behaviour of vessels in a sea-way."] These ships were under similar circumstances when the angle of roll was taken. The "Albion" rolled 49° ; the "Rodney," 27° ; the "Queen," 20° ; the "St. Vincent," 13° . In the next column you will observe the number of times that they rolled in a minute: the "Albion," 13; the "Rodney," 8; the "Queen," 7; the "St. Vincent," 5; and so on. Now the proposition of Mr. Froude is, as stated in the paper:—You may take any description of vessel, and by the adjustment of the weights you can correct any defect of rolling. That is to say, if she should roll too quickly, you can adjust that by raising the weights, so that she shall roll more slowly. But as a necessary consequence of so doing, she will roll through a larger arc. If she rolls too slowly and through a larger arc, then you can lower the weights, and the consequence is you will reduce the arc, but you will increase the rapidity of the roll. Now, in the case of the "Albion," you have got two irreconcilable things: she rolls through the largest arc, and she rolls the most quickly. Now put in practice Mr. Froude's principles. Look, for the moment, simply at the fact of her rolling 13 times in a minute. That is too fast, so you raise the weights, and, immediately, that which is already too great, viz., her depth of roll, will at once be increased. The real history of the matter is simply this, as is too much the case at the present time, mathematics and common sense, or practical knowledge, have been divorced. I have a great respect for mathematics, but it is only when they are in good hands. Mathematics are very simple in operation; the steps are very short, and any person may be taught to take all the steps; but the great difficulty is, in the application, or having got your answer, to know how to read it. Unfortunately, without a practical knowledge, or without common sense, as a rule mathematics cannot be satisfactorily applied or understood, which is the case in the present instance. Mr. Froude has made an experiment in a tin dish; to this exceptional kind of experiment he has applied his mathematics, and he has got a result which really means nothing. Now, if the statement respecting the rolling of these ships be true, and I can have no doubt about its truth, for the officers had no theory to support,—(the signal was made by the Admiral, "Take the number of the rolls and take the angle of the rolls," and they were taken and recorded, and the result returned to the Admiralty)—if that statement be true, and

you cannot for a moment imagine that it does not represent existing facts, then if you apply this theory of Mr. Froude's, you at once see its absurdity. It reminds me of a story that I once heard of a boy who demonstrated that the square of the hypotenuse of a right-angled triangle was equal to the sum of the square of the other two sides. He was not very bright; he learned to get the orthodox proof off by heart, but he drew a figure that was altogether different from the proposition he had to prove. He went off very glibly with his proof, then said, "Well, I have proved it, but I don't believe it." Now, I believe, if people were as honest as that boy, we should have such an acknowledgment with respect to many results; that there is not, I believe, simply arises from the absence of practical knowledge of the subject. Architects have undertaken to design and to build ships without practical knowledge of the subject. They ignore that altogether, while, on the other hand, sailors have been inclined to go in the opposite direction, and say, "Because I have been at sea and have got practical knowledge, I do not need any architectural knowledge; I do not need to understand the principles of mechanics, nor do I need to understand the theory of naval architecture." I believe the truth is, as Mr. Scott said, we want a combination of the two things, mathematical knowledge, and common sense, or practical knowledge applied to that. I believe this to be a very important question, and that it has been treated very satisfactorily by Mr. Barrass. I am quite satisfied that if anybody will take his paper and examine it quietly, he will see it is simple and plain. It is not a subject that is at all difficult, put in the way it is. It has been treated in a plain, common-sense way, which anybody of understanding may comprehend if he will only give himself a little trouble and very little time to study it. I am quite sure that if that be not done, and we are to be led away by the great mathematical talents and knowledge of such persons as Mr. Froude, we shall be landed in the greatest absurdities, and our ships will be utter failures. I believe we have already gone a long way in the wrong direction, and I consider the results will be very serious. Many of the points in Mr. Froude's theory it would be hardly fair to notice here, because they have not been referred to in the paper; but those which have been brought forward I have remarked upon, as showing what has been stated, that he has overlooked many of the circumstances of the case. Therefore he has applied his mathematics without considering many of the main points of the question. Mathematics are very powerful, something like a dentist's instrument, which if not rightly applied, pulls out the wrong tooth; and then the dentist has to convince the patient that he has not got the tooth-ache. Considering that Mr. Barrass is not a naval man, and has not been to sea professionally, this paper is altogether a very creditable production.

I might make a remark upon the paper from Colonel Parkinson that was first read. He proposes to put wood outside. The main object that he seems to have for this is merely for the purpose of coppering. It is a great desideratum to be able to copper a ship. A plan has been proposed by Mr. Grantham, and I think it is an excellent proposition.

There is another point in the paper which did not seem to be dwelt upon, but which I think is perfectly sound. It is to put the wood on the outside of the iron, rather than the iron outside the wood. A great point to be arrived at is to take up the intense velocity of the shot on first striking. By doing that, the shot will not penetrate the iron; but if you allow the shot to come in contact with the iron when it is at its highest velocity, it will penetrate it, and penetrate it more rapidly in proportion to the greater velocity and the greater weight of the shot. I believe wood acts more truly as a buffer when it is on the outside of the iron than when it is inside. As for the wood being destroyed by shell or by shot, that is quite immaterial, so long as the shot does not touch the real fabric of the ship. It is a complete iron ship, and then the wood is put on outside. Wood is easily repairable, and if it be destroyed it is just what you might expect. You do not expect to go into action and not have your ship knocked about; and not the ship only, but your heads too. As Sir George Sartorius said the other evening, we must be content to take our hats off, and let the shot go through.

A suggestion has been made to me by Sir Frederick Nicolson respecting Mr. Froude's system of raising and lowering weights. I gave Mr. Froude the benefit of the possibility of moving weights; but the fact is you cannot move any large weights in a ship. Take the weight of the "Warrior," a 6,000 ton ship. The weight of the hull must be something enormous. It cannot be less than three or four thousand tons. Just imagine what a large weight would be required, and what a distance you would have to raise it, to make any material difference in that ship! Why, the thing is utterly impracticable. In the remarks I have made I gave him the benefit of the possibility of doing it, but I say it would be impossible to do it from the nature of the problem, from the limitations that you are necessarily involved in in connection with the requisites of a man-of-war.

The CHAIRMAN expressed the thanks of the meeting to Mr. Barrass for the very interesting paper he had read. He had no doubt it would be of great advantage to the public service.