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XXI. Essay upon machines in general

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XXI. *Essay upon Machines in General.* By M. CARNOT,
Member of the French Institute, &c. &c.

[Concluded from vol. xxxi. p. 305.]

LXIII. **T**HESSE remarks as to the momentum of activity, have originated an idea with me of a principle of equilibrium peculiar to the case where the forces exercised in the system are attractions: I think my readers will not be displeased to find it here; it is in the following terms:

Several bodies subjected to the laws of an attraction, exercised in consequence of any function of distances, either by these bodies themselves upon each other, or by different fixed points being applied to any machine; if we make this machine pass from any given position to that of equilibrium, the momentum of activity consumed in this passage by the attractive forces with which these bodies will be animated, during this movement, will be a maximum.

That is to say, this momentum will be always greater than it would have been, if, instead of making this system pass to the position of equilibrium, we had constrained it to take a different route, and to pass into any other situation.

For example, if gravity is the subject in question, which we may regard as an attraction exercised towards a point infinitely removed, the attractive forces will be the weights applied to the machine: the momentum of activity which will be exercised by these forces when we make this machine change its situation, will therefore be equal to the total weight of the system multiplied by the height which the centre of gravity shall have descended or ascended during this change of position (XXXII). Now the situation of equilibrium is that at which the centre of gravity is at the highest or lowest point possible; therefore the height to which the centre of gravity should ascend, or from which it should descend, in order to pass from any given situation to that of equilibrium, is greater than when it has to pass to any other situation: thus the momentum of activity consumed in the passage by the motrix forces, is also greater in the first case than in any other.

If

If attraction was always constant like ordinary gravity, but, if directed towards a fixed point, placed at a finite distance, we might easily conclude from the preceding principle, that in the case of equilibrium, the sum of the momenta of the bodies of the system, relatively to this fixed point, is a maximum, *i. e.* the sum of the products of each mass, by its distance to the fixed point, is less when there is an equilibrium, than if the system was placed in any other given situation.

If the attraction towards the fixed point, instead of being constant, was proportional to the distances from this body to this fixed point, we might conclude in the same way that the sum of the products of each mass by the square of the distance to this fixed point, is a *maximum*.

We know that the sum of the products of each mass, by the square of its distance to any fixed point, is equal to the sum of the products of each mass, by the square of its distance to the centre of gravity; plus, to the product of the total mass, by the square of the distance from the centre of gravity to this fixed point: (this is a well-known proposition in geometry, and easily proved;) thus, in the case of attraction under examination, the sum of these two quantities should, in the case of equilibrium, be a *maximum*, *i. e.* its differential is equal to zero. Let us suppose, for instance, that all the parts of the system are connected with each other, so as to form only one body, and that this body is suspended by its centre of gravity, so that this point is fixed; it is clear that each of the quantities mentioned will be constant; *i. e.* will remain the same, whatever situation we give to this body, and the differential of their sum will consequently be null: thus there will be equilibrium; *i. e.* if all the particles of a body are attracted towards a fixed point, proportional to their distances to this point, and if we suspend this body by its centre of gravity, it will remain in equilibrium precisely as in the case of ordinary gravity. It must not be concluded from this, however, that in a machine to which several bodies are applied, attracted towards a fixed point, in ratio of the distances, the position of equilibrium was that at which the centre of gravity of the system would be

be at the lowest point, *i. e.* the nearest possible from the fixed point; for this only happens in the case in which all the parts of the system hold together and form but a single body: on the contrary, in the case of natural gravity, it is not necessary, in order that the centre of gravity should be at the lowest point, that the parts of the system should be united with each other.

If bodies were attracted towards the fixed point in the inverse ratio of their distances to this point, the principle alleged above would show that the situation of equilibrium is then the situation at which the sum of the products of each mass, by the logarithm from its distance to the fixed point, is a *maximum*.

In general, if the bodies m of the system are attracted in ratio of a power n , from their distances x , to this point, the situation of equilibrium will be that at which the quantity $s m x^{n+1}$ will be a *maximum*, or greater than in any other situation; *i. e.* when the difference of this quantity to what it would be, if the system was in a situation infinitely near, is equal to zero.

If there are in the system several fixed points, towards each of which the bodies m are attracted, in virtue of a power given from their distances to this point; so that x, y, z , &c. being the distances from m to these different fixed points $A x^n, B y^p, C z^q$, &c. are the central forces of m towards these different foci, it will be the quantity

$$\frac{A}{n+1} s m x^{n+1} + \frac{B}{p+1} s m y^{p+1} + \frac{C}{q+1} s m z^{q+1} + \&c. \text{ which will be a } \textit{maximum} \text{ in the position of equilibrium.}$$

And if besides this, the bodies attract each other in ratio of any given power of the distances, in such a way that X expressing the distance from the molecule m to each of the other molecules of the system, $F X^r$ is the motrix force attractive of m towards this other molecule, the situation of equilibrium will be that where the quantity

$$\frac{F}{2r+2} s m X^{r+1} + \frac{A}{n+1} s m x^{n+1} + \frac{B}{p+1} s m y^{p+1} + \frac{C}{q+1}$$

$+\frac{C}{q+1} sm \propto q+1 + \&c.$ is a *maximum*; i. e. greater than in any other situation.

It would be easy still to extend these consequences to other hypotheses of attraction; but this seems useless. I shall therefore confine myself to remarking, that we may, by a principle general to what we have shown, establish that

Whatever be the nature of the motrix forces applied to a machine, if we make it move in such a manner that it passes by the position of equilibrium, the instant when it shall arrive in this situation, will be that at which the momentum of activity consumed during the movement, by these motrix forces, shall be greatest.

That is to say, the momentum of activity which the proposed powers consume during the movement, goes on always increasing until the machine has attained the position of equilibrium; after which this momentum goes on diminishing in proportion as the system removes from this position when it has passed it; whatever, in other respects, may be the route which we make this machine assume in order to bring it to that situation.

Suppose, for example, that each of the powers applied to a machine are of a given size, and that besides this we know one of the points of direction which it should have in order that there be equilibrium: I say that this situation of equilibrium is that at which the sum of the products of each of these powers, given by the distance from the point of the machine where we suppose it applied to the fixed point given upon its direction, is the least possible*: this is easily deduced from the preceding principle.

All these things are so easily proved, after what has been said in the course of this second part, that it seems useless to dwell upon them. I shall therefore conclude this work

* It must be remarked, that in all we have said on the subject of a machine considered in different positions, and of its passage from the one to the other; it must be remarked, I say, that these positions are always supposed to be such that we pass from the one to the other by a movement which is at each instant of those I have called *geometrical*: otherwise all these propositions would be subject to the same defects with which (in V.) we have thought fit to reproach the principle of Descartes, and of several others.

with

with some reflections upon the fundamental laws from which I set out, in order to establish the theory which it contains.

Reflections upon the fundamental Laws of Equilibrium and of Movements.

Among the philosophers who have been occupied with inquiries respecting the laws of movement, some make mechanics an experimental science, others a science purely rational; *i. e.* the former, comparing the phænomena of Nature, decompose them, as it were, in order to know what they possess in common with each other, and thus to reduce them to a small number of principal facts which serve to explain all the others, and to prognosticate what should happen in every circumstance: the latter begin by hypotheses, then, reasoning consequently to their suppositions, attain the discovery of the laws which bodies would pursue in their movements, if their hypotheses were conformable to Nature; then comparing their results with the phænomena, and finding that they agree, conclude that their own hypothesis is exact, *i. e.* that bodies in fact follow the laws which they had at first only supposed.

The first of these two classes of philosophers set out therefore in their researches from the primitive notions which Nature has impressed upon us, and from experiments which she continually presents to us: the second class set out from definitions and hypotheses. With the former, the names of bodies, of powers, of equilibrium, and of movement, answer to first ideas; they cannot nor should not define them: the rest, on the contrary, having every thing to draw from their own sources, are obliged to define these terms with precision, and to explain all their suppositions clearly: but if this method seems more elegant, it is also much more difficult than the other; for there is nothing so perplexing in most of the rational sciences, and particularly in the one under consideration, as to lay down at first precise definitions, upon which no ambiguity remains: it would involve me in metaphysical discussions far above my ability, to investigate all those which have been hitherto proposed: I shall content myself with examining the first and the most simple.

What

What is a body? It is, most people will tell us, an impenetrable extent; *i. e.* which cannot be reduced to a less space. But is this property not common to the body and to the empty space? Can a cubic foot of vacuum occupy a less space? It is clear that it cannot. Suppose a cubic foot of water, for example, is contained in a vessel capable of containing two cubic feet and closed on all sides: suppose we shake or roll this vessel as much as we please, there will always remain a cubic foot of water and a cubic foot of vacuum: here are two spaces, of different nature indeed, but both equally irreducible:—it is not in this therefore that the characteristic property of bodies consists. Other people tell us that this property consists in mobility. The indefinite and empty space, say they, is immoveable, while bodies may be transported from one place of this space to another: but when the body A passes into B for example, Has not the empty space which was in B, passed into A? There is not, in my opinion, more reason for attributing the movement to the plenum which was in A, than to the vacuum which was in B; the movement consists in one of these spaces supplanting the other; and this supplanting being reciprocal, the mobility is a property which belongs no more to one than to another. Without departing from our first supposition, When I shake the vessel half empty and half full, is not the vacuum moved as well as the fluids? I dip a hollow ball of metal into a bottle; the ball goes to the bottom, Have we not here a vacuum which is moved in a plenum, in the same way as bodies are moved in a vacuum? The full space does not therefore differ from the empty space, either in mobility or in irreducibility; the impenetrability which distinguishes the first from the second, therefore, is not the same with this irreducibility; it is something which we cannot define, because it is a primitive idea!

The two fundamental laws from which I set out (XI.) are therefore truths purely experimental, and I have proposed them as such. A detailed explanation of these principles would not enter into the plan of this work, and perhaps would have only darkened the subject: the sciences are

like a beautiful stream, the course of which may be easily followed when it has acquired a certain regularity, but if we wish to ascend to its source, we shall find it in no particular spot, because it is diffused every where; it is spread in some measure over the whole surface of the earth: in the same way if we wish to ascend to the origin of the sciences, we find nothing but obscurity, vague ideas, and vitiated circles; and we are lost in primary ideas.

XXII. *Description of improved Tram-Plates for Carriages on Rail Roads.* By Mr. CHARLES LE CAAN, of Llanelly, Wales*.

SIR,

I HAVE forwarded to the Society of Arts, &c. a specimen of my new method of laying rails, or tram-plates, on such a plan as has met the entire approbation of those who have seen it, and are acquainted with the principle on which such roads should be formed. Rail roads are daily increasing, from the great advantage they afford to those manufactories connected with mines and minerals, particularly to collieries. They also promote agriculture, by occasioning lime to be procured from places almost inaccessible by any other means, or from whence it could be otherwise brought on moderate terms.

I have also sent a drawing of my method of laying the tram-plates, with an estimate of the saving that will arise to the public by adopting the said method, with necessary remarks on the principle on which it is founded. The leading rail or tram-plate has neither tenon nor mortise over the plug. The stop-plate terminates the specimen, which stop-plate should go in with some degree of tightness when laid for actual use, but in the present case that force is not necessary, as the wooden blocks, by a carriage of upwards of 200 miles, may in some small degree be misplaced. I hope

* From *Transactions of the Society for the Encouragement of Arts, Manufactures, and Commerce*, for 1807.—Twenty guineas were voted for this communication.

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