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I

Über einen Vorschlag zur Begründung der ^{Wollen} Quantenmechanik
mit Hilfe des Nernstschen Theorems.

Otto Stern

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The following considerations are based on the conviction that Nernst's Theorem is a fundamental law of nature and is really the third law of thermodynamics. Die folgenden Überlegungen beruhen auf der Überzeugung, dass Nernst's Theorem ein fundamentales Naturgesetz ist, wirklich der dritte Hauptsatz der Thermodynamik. ^{Wave mechanics is compatible with this theorem but I further believe that it should be possible, under quite general assumptions, to derive the formalism and content of wave mechanics with the help of this third law.} ~~Naturgesetz~~ gilt es für die Quantenmechanik. Ich glaube aber weiterhin, dass es möglich sein sollte den Formalismus der Quantenmechanik mit Hilfe des 3. H. abzuleiten unter sehr allgemeinen Annahmen, u. a. natürlich ^{One of the general assumptions would certainly be that classical mechanics is a limiting case of wave mechanics.} der klassischen Mechanik als Grenzfall. ^{In the following I merely attempt to present some arguments for my proposal} Ich kann das nicht beweisen und will im Folgenden nur einige Argumente für meinen Vorschlag anführen in der Hoffnung, dass jüngere und fähigere Physiker diesen Beweis ^{I am not able to prove this conjecture and so but in the following present some arguments for the validity of the proposal in the hope that a proof will be forthcoming.} durchführen werden.

Ich möchte das übliche Verfahren, den 3. H. aus der Quantenmechanik abzuleiten, umkehren. Es wird dazu wahrscheinlich erforderlich sein, den 3. H. zu verallgemeinern. Es ist z. B. naheliegend anzunehmen, dass die Entropie S gegen Null konvergiert, $S \rightarrow 0$, nicht nur für abnehmende Temperatur $T \rightarrow 0$, sondern für jeden Prozess, durch den man die Entropie eines Systems vermindert, z. B. für die isotherme Kompression eines Gases im Wärmebad.

II

Um den 3. H. auf die Mechanik anzuwenden, müssen wir Gebrauch machen von der statischen Mechanik. Dann ist die Entropie eines Systems bestimmt durch das Volumen Ω des Phasenraums, $\Omega = \int d\mathcal{V}$, also im Falle eines einzelnen Massenpunktes $\Omega = \int dp dq$ (p Impuls, q Koordinate). Der 3. H. sagt dann, dass Ω nicht verkleinert werden unter ~~über~~ einen bestimmten Grenzwert, der experimentell ~~zu~~ h bestimmt ~~ist~~ ^{ist} wird.

Wir können daher p und q ~~zusammen~~ zugleich nicht beliebig genau messen, sondern müssen annehmen, dass nur eine Wahrscheinlichkeit dafür besteht, bestimmte Werte für q und p zu finden. Diese Wahrscheinlichkeit kann nicht beliebig sein, sondern muss folgende Eigenschaft haben. Wenn wir q so genau als möglich messen, und p ~~genauer~~ als $dp = h$ so dass q ~~genauer~~ zwischen q und $q + dq$ liegt, und dann p ~~genauer~~ als $dp = \frac{dq}{dh}$ messen, so zerstören wir damit das Resultat der Messung von q . Das fordert der 3. H. wegen $dp dq > h$. Ich sehe nicht wie man dieses Verhalten scheint mir - beweisen kann ich es nicht - nur zu deuten ~~zu~~ sein als Interferenzeffect. Die Wahrscheinlichkeit muss abhängen von der Superposition von Wellen mit Phasenzusammenhang und abhängig von ~~zentriert~~ Parametern p , ~~so dass~~ ^{und} eine Messung von p diesen Zusammenhang ~~zerstört~~ ^{zerstört}. Sie schafft ~~ihre~~ ^{ihre} eine

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Superposition von p -Wellen, die ihrerseits von Parametern q abhängen. Mit andern Worten, ich vermute, dass der 3. H., angewandt auf ein mechanisches System, bereits die Abhängigkeit der Wahrscheinlichkeit von Wellenfunktionen verlangt, d. h. die Existenz ~~einer~~ von Wahrscheinlichkeitsamplituden ψ . Dass die Wahrscheinlichkeit selbst einfach $|\psi|^2$ ist, sollte aus der Forderung der klassischen Mechanik als Grenzgesetz folgen. ~~Es~~ ^{Es} scheint ~~es~~ mir berechtigt, das Ehrenfest'sche Theorem als Voraussetzung und nicht als Folgerung zu betrachten. Die ~~die~~ Beziehung zwischen Energie und Frequenz würde dabei allerdings nur indirect folgen, z. B. im Falle des Massenpunktes durch Gleichsetzen der Gruppengeschwindigkeit mit der ~~mittlere~~ makroskopischen Geschwindigkeit.

Zum Schluss möchte ich noch erwähnen, wie man den Begriff des „reinen Falles“ aus dem 3. H. direct mit Hilfe eines idealisierten Experiments ableiten kann.

Wir machen ein Moleularstrahlexperiment, bei dem wir einen Strahl in die verschiedenen Energiezustände aufspalten und jeden Zustand in einem gesonderten Gefäß auffangen. Mit einiger Idealisierung kann man ^{sich} diese Trennung als reversibel geleitet ~~betrachten~~ ^{denken}, indem man geeignete Parabelspiegel und Stempel

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sowohl am Ofen wie an den Auffängern anbringt.
The third law requires that it should be impossible to further
Der dritte Hauptsatz verlangt, dass es unmöglich sein
soll durch Benutzung einer anderen Eigenschaft
split a definite energy state. ^{by using} If we try to make this
es als dieser Energie einen ^{completely} Energiestrahle ^{determined by the energy e.g. the total angular momentum}
weiter zu spalten. Wenn die andere Eigenschaft durch
then of course we do not get any further splitting. (The property is exchangeable
die Energie bestimmt ist, z. B. das totale Impulsmoment,
with the energy.) If however we use any other property not determined by the
ist das selbstverständlich (die Eigenschaft ist, vertausch-
energy e.g. a component of angular momentum, the third law requires that
bar mit der Energie") wenn wir aber eine Eigenschaft
it is impossible to obtain any splitting without disturbing the energy
benutzen, die nicht durch die Energie bestimmt ist,
measurement. Again we have to assume interference which is destroyed by
so können wir nach dem 3. H. diese nicht mit weiteren
the measuring ~~process~~ apparatus.
Aufspaltung benutzen ohne die Energiemessung zu
zerstören. Auch hier müssen wir wieder Interferenz
zerstören und ihre Zerstörung durch die Messung annehmen.

Sollte es gelingen, die Theorie entsprechend
den obigen Andeutungen auszuarbeiten, so würde
nicht ^{nur} die Ableitung aus einem fundamentalen
thermodynamischen Satze befriedigend sein,
sondern es würde vielleicht auch helfen, noch un-
gelöste Probleme in mehr systematischer Weise
anzugreifen.

x) z. B. eine Komponente des Impulsmomentes

I

Suggestion

Wave

On a ~~proposal~~ to base Quantum mechanics on ~~Nernst's~~ Theorem

Otto Stern

Berkeley, Calif., U.S.A.

It seems to me very desirable to base Quantum Mechanics ~~as a~~ on a fundamental law as thermodynamics. I propose to take the third law of thermodynamics, Nernst's Theorem, as a basis.

Usually ~~it is~~ Nernst's Theorem ~~that~~ is derived from Quantum mechanics. ^{however} I propose to reverse this procedure. I consider Nernst's Theorem as quite fundamental, ~~really~~ ^{essentially} as the 3. law of thermodynamics.

It might ^{be} necessary for this purpose to generalise the 3. law: An evident generalisation would be the assumption that the entropy $S \rightarrow 0$ not ~~only~~ ^{only} for the temperature $T \rightarrow 0$ but for any process designed to diminish the entropy, e.g. the isothermal compression of a gas in a temperature bath.

In the following I ~~shall try~~ ^{merely attempt} to present some arguments for my proposal, the actual execution I have to leave to more competent and younger men.

To apply the 3. law to mechanics we have to use statistical mechanics. There the entropy is given by the ~~Phase~~ ^{Phase} volume $\Phi = \int dV$, or in the case of one ^{of the} ~~of the~~ ^{piece} ~~piece~~

II

mass point $\mathcal{Q} = \int dp dq$. The 3. law says that ~~the~~ \mathcal{Q} cannot be ~~made smaller than~~ ^{decreased beyond} a certain limit, experimentally determined as h . We cannot ^{simultaneously} measure q and p together ~~accurately~~ but we have only a probability of finding certain values. This probability has to be ^{so} constituted that if we measure q as ^{accurately} ~~exactly~~ as possible and then measure p ^{with greater accuracy than} ~~to better than~~ $dp = \frac{dq}{h}$, then we destroy the result of the measurement of q . This consequence of the 3. law requires — so it seems to me, but I cannot prove it — an interference effect,

This ~~that~~ means that the probability of a certain value of q is determined by the superposition of wave functions with p 's as parameters and in the right phases and that the measurement of p destroys this phaseconnection and puts in its place the corresponding superposition of wave functions with q as parameters and the right phaseconnections.

In other words, ^{I conjecture that} the third law applied to mechanics ^{already} requires the dependence of the ^{complete} probability on wave functions, ^{ie the existence of probability amplitude ψ .} That the probability is simply the absolute square $|\psi|^2$ of the probability amplitude ψ should follow from Ehrenfest's theorem which I propose to assume as a premise rather than a conclusion, ^{again} ~~reversing again the procedure~~. The connection

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between energy and frequency would thus follow rather indirectly, e.g. for the mass point by equating the group velocity to the macroscopic velocity.

Finally I ~~want~~ ^{would like} to mention how the idea of the "pure case" follows directly from an idealized experiment.

We make a molecular ray experiment by ~~sp~~ on an atom by splitting the beam into ~~the~~ different energy states and collecting every state in a different vessel.

With some idealization this experiment can be ~~was~~ ^{considered} ~~thought~~ ^{of} as reversible by using parabolic mirrors and pistons on the oven and the receivers. The 3. law ^{requires} that it should be impossible to ~~split~~ ^{of a definite energy} a beam further by using any other property of the atom. If we use a property determined by the energy (exchangeable with it), e.g. the total ^{angular momentum} ~~impuls~~ moment, we get of course no further splitting. If we use any other property, e.g. a component of the ^{angular} ~~impuls~~ -momentum, we disturb the energy measurement by destroying the phase connection which produce a definite value of the energy.

If ~~one~~ ^{could} ~~should~~ ^{it} succeed in working out the theory along the lines of the proposal ~~it~~ would not only constitute a more satisfactory foundation for quantum mechanics but might also be of help ^{giving a new approach to unsolved problems} in the ~~work on the relativistic part of the theory.~~

mechanism of permeable walls. In this way we can reach an equilibrium and the whole apparatus represents a semi-

I

On a proposal to base wave mechanics on Nernst's Theorem.

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The following considerations are ^{founded} based on the conviction that Nernst's Theorem is a fundamental law of nature and is really the third law of thermodynamics (3.L.). Wave mechanics is not only compatible with the 3.L. but I believe that it should be possible, under quite general assumptions, to derive the content and formalism of wave mechanics with the help of the 3.L. One of the general assumptions would certainly be that classical mechanics is a limiting case of ~~mechanics~~ wave mechanics. I am not able to prove my conjecture but in the following present some arguments for the validity of the proposal in the hope that a proof will be forthcoming.

Usually the 3. law is derived from wave mechanics, however I propose to reverse this procedure. It might be necessary for this purpose to generalise the 3.L.

An evident generalisation would be the assumption that the entropy $S \rightarrow 0$ not only for the temperature $T \rightarrow 0$ but for any process diminishing the entropy of a system, e.g. the isothermal compression of gas in a temperature bath.

II

To apply the 3.Q. to a mechanical system we have to use statistical mechanics. There the entropy is determined by the volume $\bar{\Omega}$ of the phase space, ~~or~~

$\bar{\Omega} = \int dV$, or in the case of one mass point $\bar{\Omega} = \int dp dq$ (q coordinate, p momentum)

We cannot measure simultaneously p and q with arbitrary accuracy but we have to assume that we have only a ~~cor~~ probability of measuring certain values.

This probability cannot be arbitrary but has to have the following property. If we measure q very accurately and find a value between q and $q+dq$ and then measure p with greater accuracy than $dp = \frac{dq}{h}$, ~~then~~ we destroy the result of the measurement of q . This consequence of the 3.Q. requires - so it seems to me - an interference effect. That means that the probability of a certain value of q is determined by the superposition of wave functions with p 's as parameters and in the right phases and that the measurement ~~of p~~ destroys this phase connection.

It puts in its place the corresponding superposition of wavefunctions with q 's as parameters and the right phases.

In other words, I conjecture that the 3.Q. applied to a mechanical system already requires the dependence of the probability ~~of~~ wavefunctions, i.e. the existence of a probability amplitude ψ . That the probability is simply the absolute square of ψ should follow from Ehrenfest's

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theorem which I propose to assume as a premise rather than a conclusion.

The connection between energy and frequency would thus follow rather indirectly, e.g. for the mass point by equating their group velocity to the macroscopic velocity.

Finally I would like to mention how the idea of the "pure case" follows directly from an idealized experiment.

We make ~~an~~ molecular ray experiment by splitting the beam into different energy states and collecting every state in a different vessel. With some idealization ^{at the separation} can be considered as reversible. The 3rd Q. requires that it should be impossible to further split a definite energy state. If we try to make this splitting using some property of the atom completely determined by the energy, e.g. the total angular momentum, then of course we do not get any further splitting. (The property is "exchangeable" with the energy.) If however we use any other property, e.g. ~~the~~ a component of angular momentum, the law requires that it is impossible to obtain any splitting without disturbing the energy measurement. Again we have to assume interference which is destroyed by the measuring apparatus.

IV

If one could succeed in working out the theory along the lines of the proposal it would not only constitute a more satisfactory foundation for wave mechanics but might also be of help in giving a new approach to unsolved problems.

x) By providing the oven and the receivers each with a parabolic mirror we can attain equilibrium. Each receiver works finally as oven and the oven as receiver. By providing pistons we get the usual arrangement ^{as} with semipermeable walls.

H.P.A.

HELVETICA PHYSICA ACTA

Birkhäuser Verlag Basel 10

Anzahl der Separata ?

Nombre de tirages à part ?

Ex.

mit, ohne Umschlag

avec, sans couverture

On a proposal to base wave mechanics on Nernst's Theoremby **Otto Stern**

Berkeley, Calif., USA

(20. II. 1962)

The following considerations are founded on the conviction that Nernst's Theorem is a fundamental law of nature and is really the third law of thermodynamics (3. L.). Wave mechanics is not only compatible with the 3. L. but I believe that it should be possible, under quite general assumptions, to derive the content and formalism of wave mechanics with the help of the 3. L. One of the general assumptions would certainly be that classical mechanics is a limiting case of wave mechanics. I am not able to prove my conjecture but in the following present some arguments for the validity of the proposal in the hope that a proof will be forthcoming.

Usually the 3. law is derived from wave mechanics, however I propose to reverse this procedure. It might be necessary for this purpose to generalize the 3. L. An evident generalization would be the assumption that the entropy $S \rightarrow 0$ not only for the temperature $T \rightarrow 0$ but for any process diminishing the entropy of a system, e.g. the isothermal compression of gas in a temperature bath.

To apply the 3. L. to a mechanical system we have to use statistical mechanics. There the entropy is determined by the volume Φ of the phase space $\Phi = \int dV$ or in the case of one mass point $\Phi = \int dp dq$ (p momentum, q coordinate). We cannot measure simultaneously p and q with arbitrary accuracy but we have to assume that we have only a probability of measuring certain values. This probability cannot be arbitrary but has to have the following property. If we measure q very accurately and find a value between q and $q + dq$ and then measure p with greater accuracy than $dp = dq/p$ we destroy the result of the measurement of q . This consequence of the 3. L. requires – so it seems to me – an interference effect. That means that the probability of a certain value of q is determined by the superposition of wave functions with p 's as parameters and

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The connection between energy and frequency would thus follow rather indirectly, e.g. for the mass point by equating the group velocity to the macroscopic velocity.

Finally I would like to mention how the idea of the 'pure case' follows directly from an idealized experiment. We make a molecular ray experiment by splitting the beam into different energy states and collecting every state in a different vessel. With some idealization the separation can be considered as reversible*). The 3. L. requires that it should be impossible to further split a definite energy state. If we try to make this splitting using some property of the atom completely determined by the energy, e.g. the total angular momentum, then of course we do not get any further splitting. (The property is 'exchangeable' with the energy.) If however we use any other property, e.g. a component of angular momentum, the law requires that it is impossible to obtain any splitting without disturbing the energy measurement. Again we have to assume interference which is destroyed by the measuring apparatus.

If one could succeed in working out the theory along the lines of the proposal it would not only constitute a more satisfactory foundation for wave mechanics but might also be of help in giving a new approach to unsolved problems.

*) By providing the oven and the receivers each with a parabolic mirror we can attain equilibrium. Each receiver works finally as oven and the oven as receiver. By providing pistons we get the usual arrangement as with semipermeable walls.

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Than the 3.L. means that Φ has a finite lower limit cannot be smaller as a limiting value experimentally determined ~~to be~~ essentially h (Planck's constant).

of ψ should follow from Ehrenfest's theorem which I propose to assume as a premise rather than a conclusion.

The connection between energy and frequency would ~~then~~ follow *from the theorem and the 3.L.* rather indirectly, e.g. for the mass point by equating the group velocity to the macroscopic velocity.

+ using $\Phi = \int d\xi dt$ (ξ energy, t time).

Finally I would like to mention how the idea of the "pure case" follows directly from an idealized experiment. We make a molecular ray experiment by splitting the beam into different energy states and collecting every state in a different vessel. With some idealization the separation can be considered as reversible.* By providing the oven and the receivers each with a parabolic mirror we can attain equilibrium. Each receiver works finally as oven and the oven as receiver. By providing pistons we get the usual arrangement as with semipermeable walls. The 3.L. requires that it should be impossible to further split a definite energy state. If we try to make this splitting using some property of the atom completely determined by the energy, e.g. the total angular momentum, then of course we do not get any further splitting. (The property is "exchangeable" with the energy.) If however we use any other property, e.g. a component of angular momentum, the law requires that it is impossible to obtain any splitting without disturbing the energy measurement. Again we have to assume interference which is destroyed by the measuring apparatus.

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If one could succeed in working out the theory along the lines of the proposal it would not only constitute a more satisfactory foundation for wave mechanics but might also be of help in giving a new approach to unsolved problems.

A Remark on Wave Mechanics and Nernst's Theorem

It is usual to derive Nernst's Theorem from Quantum Theory. I propose to reverse this procedure because I consider it as a fundamental law, the Third Law of Thermodynamics.

Furthermore I propose to generalise the theorem by assuming that the entropy S of a system goes to zero not only for the abs. temperature $T \rightarrow 0$, but that $S \rightarrow 0$ for any process used to diminish the entropy of the system, e.g. the isothermal compression of a gas.

At first sight it seems to be hopeless to try to derive the concept of the probability amplitude from thermodynamical considerations. But it seems to me to follow in a quite natural way from $S \rightarrow 0$.

Consider first the free masspoint. In this case $S \rightarrow 0$ means that the size of the phase space $\int dq dp$ has a finite limit, experimentally determined to be h ($S = k \ln \int dp dq$). We cannot measure q and p together accurately, but we have only a probability for finding certain values. This

probability has to be ~~not~~ ^{we} constituted that if ^{we} measure q as exact, as possible and make dq ~~very~~ small than $dp = \frac{dE}{dq}$ will be large. That is accomplished by considering the result of measuring q and p as produced by interference. The probability of finding a certain value of q has to be determined by the amplitude of a wave function which depends on p and vice versa ~~or~~ for p on q .

The probability itself has to be positive. Together with the requirements of the correspondence principle this should be enough to determine the "eigenfunctions" of q and p ^{and energy} as usual.

We ~~now~~ can see the connection of wave mechanics with the third law clearly in the following example.

We make a molecular ray experiment on a harmonic oscillator or an atom by splitting the beam into the different energy states and collecting every state in a different vessel, assuming it can be done in a reversible way. The third law then requires that it should not be possible to split ~~the~~ a beam of a definite energy ~~to split~~ farther. All properties which ~~are~~ determined by the energy, e.g. the total impulse moment,

fulfill this condition, they are "exchangeable" with the energy. Other properties, e.g. components of the impulse-moment, can not be measured together with the energy. Again we have to assume, that a definite value of the energy results from the interference of these properties with the right phases, and measuring them destroys the interference. This mechanism goes on and results in the "transformation theory" because the "transformation matrix" is a linear combination of "eigenfunctions".

One can the foregoing procedure ^{also} ~~of course~~ consider as the derivation of the third law from ~~of~~ the formalism of the quantum theory. But it seems to me ~~not only~~ much more satisfactory to derive this formalism by physical reasoning from a general ~~the~~ law of thermodynamics. I hope also that this approach will be helpful in applying the theory to further problems.

The value of my proposal depends of course on the possibility to work out the suggested theory, a task which I have to leave to the theoretical physicists. It is only the very first step but I believe a step in the right direction.