NOTES FOR AN AUTOBIOGRAPHY

(*Continued from page 12*)

even more generally concerning the electromagnetic foundation of physics?

Before I take this up I must briefly mention a number of investigations which relate to the Brownian motion and related objects (fluctuation-phenomena) and which in essence rest upon classical molecular mechanics. Not acquainted with the earlier investigations of Boltzmann and Gibbs, which had appeared earlier and actually exhausted the subject, I developed the statistical mechanics and the molecular-kinetic theory of thermodynamics which was based on the former. My major aim in this was to find facts which would guarantee as much as possible the existence of atoms of definite finite size.

In the midst of this I discovered that, according to atomistic theory, there would have to be a movement of suspended microscopic particles open to observation, without knowing that observations concerning the Brownian motion were already long familiar. The simplest derivation rested upon the following consideration. If the molecular-kinetic theory is essentially correct, a suspension of visible particles must possess the same kind of osmotic pressure fulfilling the laws of gases as a solution of molecules. This osmotic pressure depends upon the actual magnitude of the molecules, *i.e.*, upon the number of molecules in a gramequivalent. If the density of the suspension is inhomogeneous, the osmotic pressure is inhomogeneous, too, and gives rise to a compensating diffusion, which can be calculated from the well-known mobility of the particles. This diffusion can, on the other hand, also be considered as the result of the random displacement—unknown in magnitude originally—of the suspended particles due to thermal agitation. By comparing the amounts obtained for the diffusion current from both types of reasoning one reaches quantitatively the statistical law for those displacements, *i.e.*, the law of the Brownian motion. The agreement of these considerations with experience together with Planck's determination of the true molecular size from the law of radiation (for high temperatures) convinced the skeptics, who were quite numerous at that time (Ostwald, Mach), of the reality of atoms. The antipathy of these scholars towards atomic theory can indubitably be traced back to their positivistic philosophical attitude.

This is an interesting example of the fact that even scholars of audacious spirit and fine instinct can be obstructed in the interpretation of facts by philosophical prejudices. The prejudice—which has by no means died out in the meantime—consists in the faith that facts by themselves can and should yield scientific knowledge without free conceptual construction. Such a misconception is possible only because one does not easily become aware of the free choice of such concepts, which, through verification and long usage, appear to be immediately connected with the empirical material.

REFLECTIONS of this type made it clear to me as long ago as shortly after 1900, *i.e.*, shortly after Planck's trail-blazing work, that neither mechanics nor thermodynamics could (except in limiting cases) claim exact validity. By and by I despaired of the possibility of discovering the true laws by means of constructive efforts based on known facts. The longer and the more despairingly I tried, the more I came to the conviction that only the discovery of a universal formal principle could lead us to assured results. The example I saw before me was thermodynamics. The general principle was there given in the theorem: the laws of nature are such that it is impossible to construct a *perpetuum mobile* (of the first and second kind). How, then, could such a universal principle be found? After ten years of reflection such a principle resulted from a paradox upon which I had already hit at the age of sixteen: if I pursue a beam of light with the velocity *c* (velocity of light in a vacuum), I should observe such a beam of light as a spatially oscillatory electromagnetic field at rest. However, there seems to be no such thing, whether on the basis of experience or according to Maxwell's equations. From the very beginning it appeared to me intuitively clear that, judged from the standpoint of such an observer, everything would have to happen according to the same laws as for an observer who, relative to the earth, was at rest. For how, otherwise, should the first observer know, *i.e.*, be able to determine, that he is in a state of fast uniform motion?

One sees that in this paradox the

Your Literary I. Q.

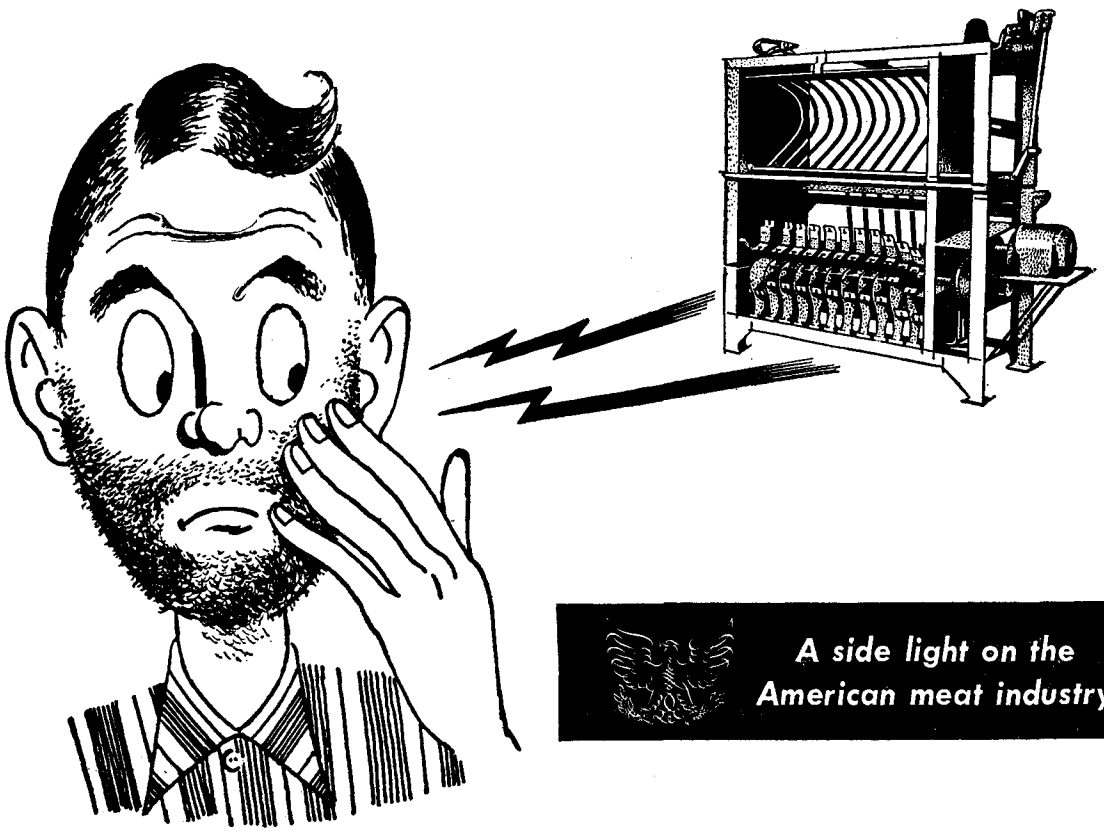
By Howard Collins

MORE GILBERT & SULLIVAN

L. L. Emery, of Durham Center, Conn., submits quotations in which various G & S characters identify themselves in songs or remarks. Can you also identify them? Allowing four points for each correct answer, a score of sixty is par, seventy-two is very good, and eighty or better is excellent. Answers are on page 46.

1. "I am a mad wag—the merriest dog that barks."
2. "I am in reasonable health, and happy to meet you all once more."
3. "I think I am sufficiently decayed."
4. "I'm an everyday young man."
5. "I'm afraid I'm not equal to the intellectual pressure of the conversation."
6. "I am a maiden, cold and stately."
7. "A king of autocratic power we."
8. "I can trick you into learning with a laugh."
9. "I am an intellectual chap."
10. "I can write a washing bill in Babylonic cuneiform."
11. "Ah! bitter is my lot!"
12. "To indulge my lamentation no occasion do I miss."
13. "I smoke like a furnace, I'm always in liquor."
14. "The lark and the clerk, I remark, comfort me not."
15. "I always eat peas with a knife."
16. "My nature is love and light."
17. "I was born sneering."
18. "I once was as meek as a new-born lamb."
19. "I'm the slave of the gods, neck and heels."
20. "I find my duty hard to do today."
21. "I went to the bar as a very young man."
22. "And many a burglar I've restored to his friends and his relations."
23. "I respect your Republican fallacies."
24. "I can tell a woman's age in half a minute."
25. "I do not care for dirty greens, by any means."

INTERESTED IN A FASTER SHAVE?



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germ of the special relativity theory is already contained. Today everyone knows, of course, that all attempts to clarify this paradox satisfactorily were condemned to failure as long as the axiom of the absolute character of time, *viz.*, of simultaneity, unrecognizedly was anchored in the unconscious. Clearly to recognize this axiom and its arbitrary character really implies already the solution of the problem. The type of critical reasoning which was required for the discovery of this central point was decisively furthered, in my case especially, by the reading of David Hume's and Ernst Mach's philosophical writings.

ONE had to understand clearly what the spatial coordinates and the temporal duration of events meant in physics. The physical interpretation of the spatial coordinates presupposed a fixed body of reference, which, moreover, had to be in a more or less definite state of motion (inertial system). In a given inertial system the coordinates meant the results of certain measurements with rigid (stationary) rods. (One should always be conscious of the fact that the presupposition of the existence in principle of rigid rods is a presupposition suggested by approximate experience, but which is, in principle, arbitrary.) With such an interpretation of the spatial coordinates the question of the validity of Euclidean geometry becomes a problem of physics.

If, then, one tries to interpret the time of an event analogously, one needs a means for the measurement of the difference in time (in itself determined periodic process realized by a system of sufficiently small spatial extension). A clock at rest relative to the system of inertia defines a local time. The local times of all space points taken together are the "time," which belongs to the selected system of inertia, if a means is given to "set" these clocks relative to each other. One sees that *a priori* it is not at all necessary that the "times" thus defined in different inertial systems agree with one another. One would have noticed this long ago, if, for the practical experience of everyday life light did not appear (because of the high value of c), as the means for the statement of absolute simultaneity.

The presupposition of the existence (in principle) of (ideal, *viz.*, perfect) measuring rods and clocks is not independent of each other; since a lightsignal, which is reflected back and forth between the ends of a rigid rod, constitutes an ideal clock, provided that the postulate of the

constancy of the light-velocity in vacuum does not lead to contradictions.

The above paradox may then be formulated as follows. According to the rules of connection, used in classical physics, of the spatial coordinates and of the time of events in the transition from one inertial system to another the two assumptions of

(1) the constancy of the light velocity

(2) the independence of the laws (thus specially also of the law of the constancy of the light velocity) of the choice of the inertial system (principle of special relativity)

are mutually incompatible (despite the fact that both taken separately are based on experience).

The insight which is fundamental for the special theory of relativity is this: the assumptions (1) and (2) are compatible if relations of a new type ("Lorentz-transformation") are postulated for the conversion of coordinates and the times of events. With the given physical interpretation of coordinates and time, this is by no means merely a conventional step, but implies certain hypotheses concerning the actual behavior of moving measuring-rods and clocks, which can be experimentally validated or disproved.

The universal principle of the special theory of relativity is contained in the postulate: the laws of physics are invariant with respect to the Lorentz-transformations (for the transition from one inertial system to any other arbitrarily chosen system of inertia). This is a restricting principle for natural laws, comparable to the restricting principle of the non-existence of the *perpetuum mobile* which underlies thermodynamics.

First a remark concerning the relation of the theory to "four-dimensional space." It is a widespread error that the special theory of relativity is supposed to have, to a certain extent, first discovered, or at any rate, newly introduced, the four-dimensionality of the physical continuum. This, of course, is not the case. Classical mechanics, too, is based on the four-dimensional continuum of space and time. But in the four-dimensional continuum of classical physics the subspaces with constant time value have an absolute reality, independent of the choice of the reference system. Because of this [fact], the four-dimensional continuum falls naturally into a three-dimensional and a one-dimensional (time), so that the four-dimensional

point of view does not force itself upon one as *necessary.* The special theory of relativity, on the other hand, creates a formal dependence between the way in which the spatial coordinates, on the one hand, and the temporal coordinates, on the other, have to enter into the natural laws.

MINKOWSKI'S important contribution to the theory lies in the following: before Minkowski's investigation it was necessary to carry out a Lorentz-transformation on a law in order to test its invariance under such transformations; he, on the other hand, succeeded in introducing a formalism such that the mathematical form of the law itself guarantees its invariance under Lorentz-transformations. By creating a four-dimensional tensor-calculus he achieved the same thing for the four-dimensional space which the ordinary vector-calculus achieves for the three spatial dimensions. He also showed that the Lorentz-transformation (apart from a different algebraic sign due to the special character of time) is nothing but a rotation of the coordinate system in the four-dimensional space.

First, a remark concerning the theory as it is characterized above. One is struck [by the fact] that the theory (except for the four-dimensional space) introduces two kinds of physical things, *i.e.,* (1) measuring rods and clocks, (2) all other things, *e.g.,* the electro-magnetic field, the material point, etc. This, in a certain sense, is inconsistent; strictly speaking measuring rods and clocks would have to be represented as solutions of the basic equations (objects consisting of moving atomic configurations), not, as it were, as theoretically self-sufficient entities. However, the procedure justifies itself because it was clear from the very beginning that the postulates of the theory are not strong enough to deduce from them sufficiently complete equations for physical events sufficiently free from arbitrariness, in order to base upon such a foundation a theory of measuring rods and clocks. If one did not wish to forego a physical interpretation of the coordinates in general (something which, in itself, would be possible), it was better to permit such inconsistency—with the obligation, however, of eliminating it at a later stage of the theory. But one must not legalize the mentioned sin so far as to imagine that intervals are physical entities of a special type, intrinsically different from other physical variables ("reducing physics to geometry," etc.).

We now shall inquire into the insights of definite nature which phys-

ics owes to the special theory of relativity.

(1) There is no such thing as simultaneity of distant events; consequently there is also no such thing as immediate action at a distance in the sense of Newtonian mechanics. Although the introduction of actions at a distance, which propagate with the speed of light, remains thinkable, according to this theory, it appears unnatural; for in such a theory there could be no such thing as a reasonable statement of the principle of conservation of energy. It therefore appears unavoidable that physical reality must be described in terms of continuous functions in space. The material point, therefore, can hardly be conceived any more as the basic concept of the theory.

(2) The principles of the conservation of momentum and of the conservation of energy are fused into one single principle. The inert mass of a closed system is identical with its energy, thus eliminating mass as an independent concept.

Remark. The speed of light c is one of the quantities which occurs as "universal constant" in physical equations. If, however, one introduces as unit of time instead of the second the time in which light travels 1 cm, c no longer occurs in the equations. In this sense one could say that the constant c is only an *apparently* universal constant.

It is obvious and generally accepted that one could eliminate two more universal constants from physics by introducing, instead of the gram and the centimeter, properly chosen "natural" units (for example, mass and radius of the electron).

If one considers this done, then only "dimension-less" constants could occur in the basic equations of physics. Concerning such I would like to state a theorem which at present cannot be based upon anything more than upon a faith in the simplicity, *i.e.*, intelligibility, of nature: there are no *arbitrary* constants of this kind; that is to say, nature is so constituted that it is possible logically to lay down such strongly determined laws that within these laws only rationally completely determined constants occur (not constants, therefore, whose numerical value could be changed without destroying the theory).

The special theory of relativity owes its origin to Maxwell's equations of the electromagnetic field. Inversely the latter can be grasped formally in satisfactory fashion only by way of the special theory of relativity. Maxwell's equations are the simplest Lorentz-invariant field equations

which can be postulated for an antisymmetric tensor derived from a vector field. This in itself would be satisfactory, if we did not know from quantum phenomena that Maxwell's theory does not do justice to the energetic properties of radiation. But how Maxwell's theory would have to be modified in a natural fashion, for this even the special theory of relativity offers no adequate foothold. Also to Mach's question: "How does it come about that inertial systems are physically distinguished above all other coordinate systems?" this theory offers no answer.

That the special theory of relativity is only the first step of a necessary development became completely clear to me only in my efforts to represent gravitation in the framework of this theory. In classical mechanics, interpreted in terms of the field, the potential of gravitation appears as a *scalar* field (the simplest theoretical possibility of a field with a single component). Such a scalar theory of the gravitational field can easily be made invariant under the group of Lorentz-transformations. The following program appears natural, therefore: the total physical field consists of a scalar field (gravitation) and a vector field (electromagnetic field); later insights may eventually make necessary the introduction of still more complicated types of fields; but to begin with one did not need to bother about this.

The possibility of the realization of this program was, however, dubious from the very first, because the theory had to combine the following things:

(1) From the general considerations of special relativity theory it was clear that the *inert* mass of a physical system increases with the total energy (therefore, *e.g.*, with the kinetic energy).

(2) From very accurate experiments (specially from the torsion balance experiments of Eötvös) it was empirically known with very high accuracy that the gravitational mass of a body is exactly equal to its *inert* mass.

It followed from (1) and (2) that the *weight* of a system depends in a precisely known manner on its total energy. If the theory did not accomplish this or could not do it naturally, it was to be rejected. The condition is most naturally expressed as follows: the acceleration of a system falling freely in a given gravitational field is independent of the nature of the falling system (specially therefore also of its energy content).

It then appeared that in the framework of the program sketched this elementary state of affairs could not at all or at any rate not in any natural fashion, be represented in a satisfactory way. This convinced me that within the frame of the special theory of relativity there is no room for a satisfactory theory of gravitation.

Now it came to me: the fact of the equality of inert and heavy mass, *i.e.*, the fact of the independence of the gravitational acceleration of the nature of the falling substance, may be expressed as follows: in a gravitational field (of small spatial extension) things behave as they do in a space free of gravitation, if one introduces in it, in place of an "inertial system," a reference system which is accelerated relative to an inertial system.

If then one conceives of the behavior of a body, in reference to the latter reference system, as caused by a "real" (not merely apparent) gravitational field, it is possible to regard this reference system as an "inertial system" with as much justification as the original reference system.

So, if one regards as possible, gravitational fields of arbitrary extension which are not initially restricted by spatial limitations, the concept of the "inertial system" becomes completely empty. The concept, "acceleration relative to space," then loses every meaning and with it the principle of inertia together with the entire paradox of Mach.

The fact of the equality of inert and heavy mass thus leads quite naturally to the recognition that the basic demand of the special theory of relativity (invariance of the laws under Lorentz-transformations) is too narrow, *i.e.*, that an invariance of the laws must be postulated also relative to *non-linear* transformations of the coordinates in the four-dimensional continuum.

This happened in 1908. Why were another seven years required for the construction of the general theory of relativity? The main reason lies in the fact that it is not so easy to free oneself from the idea that coordinates must have an immediate metrical meaning. The transformation took place in approximately the following fashion.

We start with an empty, field-free space, as it occurs—related to an inertial system—in the sense of the special theory of relativity, as the simplest of all imaginable physical situations. If we now think of a non-inertial system introduced by assuming that the new system is uniformly

accelerated against the inertial system (in a three-dimensional description) in one direction (conveniently defined), then there exists with reference to this system a static parallel gravitational field. The reference system may thereby be chosen as rigid, of Euclidian type, in three-dimensional metric relations. But the time, in which the field appears as static, is *not* measured by *equally constituted* stationary clocks. From this special example one can already recognize that the immediate metric significance of the coordinates is lost if one admits non-linear transformations of coordinates at all. To do the latter is, however, *obligatory* if one wants to do justice to the equality of gravitational and inert mass by means of the basis of the theory, and if one wants to overcome Mach's paradox as concerns the inertial systems.

If, then, one must give up the attempt to give the coordinates an immediate metric meaning (differences of coordinates = measurable lengths, *viz.*, times), one will not be able to avoid treating as equivalent all coordinate systems, which can be created by the continuous transformations of the coordinates.

The general theory of relativity, accordingly, proceeds from the following principle: natural laws are to be expressed by equations which are covariant under the group of continuous coordinate transformations. This group replaces the group of the Lorentz-transformations of the special theory of relativity, which forms a sub-group of the former.

If anything in the theory as sketched—apart from the demand of the invariance of the equations under the group of the continuous coordinate-transformations—can possibly make the claim to final significance, then it is the theory of the limiting case of the pure gravitational field and its relation to the metric structure of space. For this reason, in what immediately follows we shall speak only of the equations of the pure gravitational field.

The peculiarity of these equations lies, on the one hand, in their complicated construction, especially their non-linear character as regards the field-variables and their derivatives, and, on the other hand, in the almost compelling necessity with which the transformation-group determines this complicated field-law. If one had stopped with the special theory of relativity, *i.e.*, with the invariance under the Lorentz-group, then the field-law $R_{ik} = 0$ would remain invariant also within the frame of this narrower group. But from the point

of view of the narrower group there would at first exist no reason for representing gravitation by so complicated a structure as is represented by the symmetric tensor g_{ik}. If, nonetheless, one would find sufficient reasons for it, there would then arise an immense number of field-laws out of quantities g_{ik}, all of which are covariant under Lorentz-transformations (not, however, under the general group). However, even if, of all the conceivable Lorentz-invariant laws, one had accidentally guessed precisely the law which belongs to the wider group, one would still not be on the plane of insight achieved by the general principle of relativity. For, from the standpoint of the Lorentz-group two solutions would incorrectly have to be viewed as physically different from each other, if they can be transformed into each other by a non-linear transformation of coordinates, *i.e.*, if they are, from the point of view of the wider field, only different representations of the same field.

I must take a stand with reference to the most successful physical theory of our period, *viz.*, the statistical quantum theory which, about twenty-five years ago, took on a consistent logical form (Schrödinger, Heisenberg, Dirac, Born). This is the only theory at present which permits a unitary grasp of experiences concerning the quantum character of micro-mechanical events. This theory, on the one hand, and the theory of relativity on the other, are both considered correct in a certain sense, although their combination has resisted all efforts up to now. This is probably the reason why among contemporary theoretical physicists there exist entirely differing opinions concerning the question as to how the theoretical foundation of the physics of the future will appear. Will it be a field theory; will it be in essence a statistical theory? I shall briefly indicate my own thoughts on this point.

Physics is an attempt conceptually to grasp reality as it is thought independently of its being observed. In this sense one speaks of "physical reality." In pre-quantum physics there was no doubt as to how this was to be understood. In Newton's theory reality was determined by a material point in space and time; in Maxwell's theory, by the field in space and time. In quantum mechanics it is not so easily seen.

This exposition has fulfilled its purpose if it shows the reader how the efforts of a life hang together and why they have led to expectations of a definite form.

the Phoenix Nest

POVERTY

BEYOND the heights
Where the pavement ends and dust begins,
Lives Poverty in seven shacks.
Creditor to her neighbor,
Stepmother to her children,
Despised and despiser.
The hag of the matted hair,
Blue-veined hands
And elbows like roosters' spurs,
Sips the porridge of inertia
From the tin spoon of resignation.

In the bright and dark of the moon,
In the cloud-blinded and gold-clear sun,
Poverty can be seen from every direction—
But not by the inhabitants of the heights.
For if they look down the bridge of their noses,
All they can see is the curl of their upper lips.

—ROSA ZAGNONI MARINONI.

* * *

The following fascinates me. It is not jabber-wocky, but correct according to Webster. The author's name, too, seems to blend. The other day we found a dead mole on the garden path, prey to a cat. Hence:

MOLE

As the didapper questions the mole-fume,*
Far from dabchick or other small grebe,
The gears of the day, disengaging,
Enmesh the malaise of the glebe.

But careless of bird-quest, the delver,
The mole with controllable glands
Makes fume as he fondles the wortroot,
Grows manic as foxglove† demands.

Let bird-flourish‡ curdle the ether,
Let pistils importune the star;
Oh desman with forefeet fossorial,
Dredge sooth from the soil that you are!

—S. TALP FELKER.

* * *

It has come to my attention that a modest book priced at one simoleon and purporting to be by the initialed authors W. R. B. and C. M. is a gallimaufry of gambols worthy of the one-buck expenditure. It is "breathed through" that the publisher responsible for this mysterious hanaper of haps (soon to be marketed) is one Louis Greenfield of 45 E. 17th St., New York 3, N. Y., to whom should be addressed all correspondence concerning this forthcoming collectors' item. Further deponent saith not, save that an eminent ex-historian of literature has written for it a surpassing preface over the signature "Cuckoo," inasmuch as the text of this poetry package is laid to the joint efforts of a pigeon and a dove! Yes, the contents is verse, veritably a nosegay of the most singular—and some disturbing—conceits. *Exit atiptoe!*

* Odor emitted, as from flowers.
† Yields the important drug digitalis.
‡ Boast, vaunt, brag.

* * *

SLEEVELESS ERRAND

Their marriage lasted twenty years;
They followed separate careers.

Lately they parted, without regret,
Unaware they had never met.

—ELISE S. PECKHAM.

* * *

An unusual cookbook that I have brought down with me from Cape Ann owes its publication to the initiative of St. Mary's Episcopal Church in Rockport, Massachusetts. It is paper-bound, with metal rings, which makes it particularly easy to consult. It is edited by Ruth Langland Holberg, who wrote "Take It Easy Before Dinner." It contains personal recipes by such well-known people as our own Amy Loveman, Dorothy Heyward, the playwright, S. L. M. Barlow, Mrs. Paul Manship, Mrs. Harrison Cady, Esther Williams the painter (not the swimmer!), Mrs. Gifford Beal, Marjorie Flack, and your ever-hungry editor, as well as by members of the parish noted for their New England cooking. Back in my apartment I intend to try Fish Muddle, Policemen's Meat Loaf, Post Office Kisses, Witch House Casserole, Fireman's Pork Chops, as well as our own Angling Point Lobster. If interested, anyone may write to St. Mary's Church, Rockport. The book costs two dollars.

* * *

ALL FOWLED UP

Remember that bird of Poe's he said was a raven?
Well, judging by the way it was behavin',