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**ABDUS
SALAM**
(WITH COMMENTARY)

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World Scientific Series in 20th Century Physics – Vol. 5

Selected Papers of
ABDUS
SALAM
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World Scientific

Singapore • New Jersey • London • Hong Kong

Published by

World Scientific Publishing Co. Pte. Ltd.

P O Box 128, Farrer Road, Singapore 9128

USA office: Suite 1B, 1060 Main Street, River Edge, NJ 07661

UK office: 73 Lynton Mead, Totteridge, London N20 8DH

Library of Congress Cataloging-in-Publication Data

Salam, Abdus, 1926–

Selected papers of Abdus Salam : with commentary / editors, A. Ali

... [et al.].

p. cm. -- (World scientific series in 20th century physics ;
vol. 5)

Includes bibliographical references.

ISBN 9810216629 9810216637 (pbk)

1. Particles (Nuclear physics). 2. Electroweak interactions.
3. Grand unified theories (Nuclear physics). 4. Quantum field
theory. I. Ali, A. (Ahmed) II. Title. III. Series.

QC793.2.S25 1994

530.1'43--dc20

94-2323

CIP

The editors and publisher would like to thank the following publishers of the various journals and books for their assistance and permissions to include the selected reprints found in this volume:

Academic Press

American Physical Society

Cambridge University Press

Elsevier Science Publishers B.V.

John Wiley and Sons

Macmillan Magazines Ltd.

The Nobel Foundation

Royal Soc. London

Società Italiana di Fisica

Springer Verlag

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Printed in Singapore by Singapore National Printers Ltd

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Introduction

Abdus Salam is one of the leading theoretical physicists of his generation. His 275 published papers span a huge range and contain many seminal contributions. It is quite impossible to include all the important papers in a single volume. As editors, we have had to make very difficult choices, omitting many papers that we would have wished to accommodate. We have tried to include representatives of all the different periods of his work and all the different fields to which he contributed, though inevitably some are better represented than others.

The papers appear in roughly chronological order, but they have been grouped into five broad sections, each representing a different major strand in his work.

Abdus Salam was born in Jhang, now in Pakistan, one of the least developed areas of a developing country. Before leaving for England, his name was already a legend in his home country as, in the fierce competition of pre-partition India, he passed every examination at Punjab University, Lahore with the creation of a new record.

Salam came to Cambridge in 1946. Following a brilliant undergraduate career, he began research in the Cavendish Laboratory in 1949 at a most opportune moment. During the second world war, many of the leading theoretical physicists had been involved in the Manhattan project or other work for the war effort. When the war ended they returned to their universities to attack with renewed vigour the problems they had left behind, including the intractable problem of infinities in quantum electrodynamics (QED). There was a sudden surge of progress, most notably the development of renormalization theory, which showed how to control the infinities by absorbing them into corrections to the observable parameters of the theory, the mass and charge of the electron.

When Salam graduated, he asked Nicholas Kemmer to take him on as a research student. Kemmer told him that all the fundamental problems of making QED finite had been solved by Shin-ichiro Tomonaga, Julian Schwinger, Richard Feynman and Freeman Dyson, and that Paul Matthews, then just completing his PhD, had nearly done the same for spin-zero meson theory, but might have some problems left. Matthews had proved renormalizability to lowest order and suggested that Salam try to extend the proof to higher orders. He was amazed when Salam returned almost at once with a solution to one of the outstanding difficulties, the problem of 'overlapping divergences'. Matthews became Salam's PhD supervisor and they worked together on the problem. Thus began one of the longest-lasting and most productive collaborations of Salam's career.

Salam's work made an immediate impact. He was at once recognized as a major contributor to the field. Following a brief visit to Princeton and a three-year spell as professor at his *alma mater*, Government College, Lahore, and Head of the Mathematics Department in Panjab University, he returned to Cambridge as a lecturer in 1954 and was appointed Professor of Theoretical Physics at Imperial College in 1957 at the age of 30. During this period he made some of the key advances in quantum field theory, especially concerning proofs of renormalizability and extending the validity of dispersion relations. These papers constitute the bulk of the first section of the collection.

Following the successful description of electromagnetic interactions by QED, physicists sought to apply similar ideas to the other fundamental interactions — the strong and weak nuclear forces and gravity. Salam made one of the key early advances in developing a theory of weak interactions when he introduced the γ_5 invariance principle for neutrinos, leading to the two-component theory of the neutrino. Since the triumph of QED, the greatest advance in fundamental theoretical physics has been the development in the 60s and 70s of the unified theory of weak and electromagnetic interactions, a gauge theory based on the symmetry group $SU(2) \times U(1)$. Abdus Salam played a major role, recognized by his sharing the 1979 Nobel Prize for Physics with Sheldon Glashow and Steven Weinberg. Salam's contributions in this field are represented by the papers in Sec. 2.

Once again this success was a spur to further work, a challenge to extend still further the ideas of unification. The next two sections of the book represent two different directions in which Salam sought to go beyond the electroweak theory.

One obvious question was: is it possible to develop a unified theory that embraces not only electromagnetic and weak interactions, but the strong interactions too? By this time, physicists had a good understanding of both electroweak and strong interactions separately. Both are described by gauge theories — in the case of the strong interactions, by quantum chromodynamics (QCD), based on the symmetry group $SU(3)$. According to this theory the strongly interacting particles, or hadrons, are seen as composed of quarks, held together by exchange of gluons. Thus the proton and neutron are each made of three quarks, and the pion of a quark-antiquark pair. So theorists started to look for a 'grand unified theory' that would combine the symmetries of the strong and electroweak theories, $SU(3) \times SU(2) \times U(1)$, into a single larger group, a symmetry that would unite the quarks and the leptons (the electron, muon, tauon and neutrinos). One such proposal, due to Jogesh Pati and Salam, is described in the papers collected in Sec. 3. This was an influential and fascinating development.

The greatest remaining challenge to theoretical physics is to bring gravity within the same framework as the other interactions. So far, a viable quantum theory of

gravity eludes us. Though we have an excellent classical theory of gravity — Albert Einstein's general theory of relativity — it cannot be quantized; the attempt leads to irremovable infinities.

One possible direction of escape is to change the classical theory, replacing general relativity by 'supergravity' or 'superstring theory'. One of the key ideas here is *supersymmetry*, which relates fermions to bosons. Though there is no direct experimental evidence for supersymmetry, there are indirect hints, and it is theoretically a most attractive hypothesis, which does much to tame the infinities. Even more radically, string theory postulates that the most fundamental entities are not point-like but extended, one-dimensional objects. This too helps to tame the infinities. It is possible that by some combination of these ideas we will eventually reach a viable theory, not only embracing a quantum theory of gravity, but also uniting all four interactions in a 'theory of everything' — though this still remains a distant hope. Section 4 contains a number of major contributions by Salam and his collaborators to these developments.

The final section, devoted to some of Salam's most recent work, illustrates both the breadth of his interests and the continuing originality of his ideas. Unlike most of his previous research, these papers are not concerned with elementary particles but with fundamental problems in condensed matter physics and biology.

One of the most exciting developments in the condensed matter field in recent years was the discovery of materials that are superconducting up to relatively high temperatures. Whereas the mechanism of superconductivity in conventional metallic superconductors is now well understood, there is as yet no accepted theory for the mechanism of high-temperature superconductivity. The papers presented here describe a very promising line of attack, involving field theories restricted to two spatial dimensions, corresponding to the layered structure of these materials.

Also included are two papers proposing a solution to one of the long-standing puzzles of evolutionary biology — the origin of chirality or handedness in biological molecules.

Each of the five sections is preceded by a brief introduction, setting the scene for the papers that follow.

The editors are very conscious of the omissions from this volume. Many important papers, especially long ones, had to be eliminated to keep the total number of pages within bounds. However, a complete list of Salam's published papers is included from which those we could not accommodate can be found.

The volume also omits all Salam's many wider contributions — to debates on science policy, development in the third world, international peace, and so on. Many of these have already appeared in other collections.

We are grateful to numerous colleagues for their advice about what should be included, and only regret that we were unable to accept all their suggestions.

Ahmed Ali
Christopher Isham
Tom Kibble
Riazuddin

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