

Since the advent of the nuclear reactor, thermal neutron scattering has proved a valuable tool for studying many properties of solids and liquids, and research workers are active in the field at reactor centres and universities throughout the world.

This classic text provides the basic quantum theory of thermal neutron scattering and applies the concepts to scattering by crystals, liquids and magnetic systems. Other topics discussed are the relation of the scattering to correlation functions in the scattering system, the dynamical theory of scattering and polarisation analysis. No previous knowledge of the theory of thermal neutron scattering is assumed, but basic knowledge of quantum mechanics and solid state physics is required.

The book is intended for experimenters rather than theoreticians, and the discussion is kept as informal as possible. A number of examples, with worked solutions, are included as an aid to the understanding of the text.

Gordon L. Squires (1924-2010) was a Lecturer in Physics at the University of Cambridge and a Fellow of Trinity College Cambridge from 1956. He published two other books with Cambridge University Press: *Practical Physics* and *Problems in Quantum Mechanics with Solutions*, wrote an article on quantum mechanics for the *Encyclopaedia Britannica* and contributed extensively to leading scientific journals. From his retirement in 1991 until his death in 2010, Dr Squires was the curator of the Cavendish Laboratory Museum and wrote a number of historical articles on scientists and scientific discoveries in Cambridge.

**CAMBRIDGE**  
UNIVERSITY PRESS  
[www.cambridge.org](http://www.cambridge.org)

ISBN 978-1-107-64406-9



9 781107 644069 >



## **1 Introduction**

- 1.1 Basic properties of the neutron 1
- 1.2 Numerical values for velocity, energy, wavelength 2
- 1.3 Definitions of scattering cross-sections 5
- 1.4 Scattering of neutrons by a single fixed nucleus 7

## **2 Nuclear scattering – basic theory**

- 2.1 Introduction 10
- 2.2 Fermi's golden rule 10
- 2.3 Expression for  $d^2\sigma/d\Omega dE'$  13
- 2.4 Coherent and incoherent scattering 21

## **3 Nuclear scattering by crystals**

- 3.1 Introduction 25
- 3.2 Normal modes 26
- 3.3 Probability function for a harmonic oscillator 27
- 3.4 Development of  $\langle \exp U \exp V \rangle$  28
- 3.5 Phonon expansion 30
- 3.6 Coherent elastic scattering 32
- 3.7 Coherent one-phonon scattering 43
- 3.8 Coherent multiphonon scattering 53
- 3.9 Incoherent scattering 54
- 3.10 Multiphonon cross-sections – approximation methods 57
- Examples 59



<b>4</b>	<b>Correlation functions in nuclear scattering</b>	
4.1	Definitions of $I(\kappa, t)$ , $G(r, t)$ , and $S(\kappa, \omega)$	61
4.2	Expressions for $G(r, t)$ and $G_s(r, t)$	63
4.3	Analytic properties of the correlation functions	65
4.4	Principle of detailed balance	68
4.5	Scattering from a single free nucleus	70
4.6	Moments of the scattering function	73
4.7	Relation between elastic scattering and $I(\kappa, \infty)$ , $G(r, \infty)$	75
4.8	Static approximation	78
	Examples	84
<b>5</b>	<b>Scattering by liquids</b>	
5.1	Introduction	86
5.2	No elastic scattering	87
5.3	Coherent scattering	88
5.4	Incoherent scattering	96
<b>6</b>	<b>Neutron optics</b>	
6.1	Refractive index	110
6.2	Neutron reflection	114
6.3	Dynamical theory of scattering	116
	Examples	128
<b>7</b>	<b>Magnetic scattering – basic theory</b>	
7.1	Preliminary results	129
7.2	Expression for $d^2\sigma/d\Omega dE'$	131
7.3	Scattering due to spin only	137
7.4	Scattering by ions with spin and orbital angular momentum	139
7.5	Time-dependent operators	139
7.6	Cross-section for a paramagnet	143
	Examples	144
<b>8</b>	<b>Scattering from magnetically ordered crystals</b>	
8.1	Elastic magnetic scattering	146
8.2	Scattering by spin waves	155
	Examples	169
<b>9</b>	<b>Polarisation analysis</b>	
9.1	Introduction	171
9.2	Nuclear scattering	172



9.3	Magnetic scattering	177
9.4	Bragg scattering from magnetically ordered crystals	181
9.5	Scattering by the atomic electric field	188
	Examples	194

## **Appendices**

A	The Dirac delta function	196
B	Fourier transforms	201
C	Some results for linear operators and matrix elements	204
D	Heisenberg operators	207
E	The harmonic oscillator in quantum mechanics	210
F	Angular momentum in quantum mechanics	215
G	Normal modes of crystals	218
H	The proofs of two results for magnetic scattering	226
I	Some mathematical results	229

*Solutions to examples* 231

*Bibliography* 241

*References* 243

*Glossary of symbols* 247

*Index* 255