expected from the assumptions of the models and this is a very distinctive feature of the book.

Of a somewhat less distinctive character, but still very useful, are short accounts given of other models. The droplet model, which views the scattering as determined by the extended nature of the particles and is particularly successful in describing elastic momentum transfer distributions, is briefly treated and some possible modifications indicated. Various statistical models ranging from simple phase space modified by the empirical cutoff on high transverse momentum to the statistical bootstrap model of Hagedorn and Frautschi, which connects this cutoff to the resonance spectrum and dual resonance models in an intriguing way, are sketched. Models with diffraction as the sole mode of particle production, now experimentally disfavoured, are critically presented; the expectations, on different assumptions as to which clusters are initially produced, for final state charge distributions are extensively analysed and thermodynamical analogies for the two component model of Wilson mentioned earlier are presented briefly. These analogies have led to the multiperipheral component of this model being referred to as a Feynman gas and, though phenomenological applications of ideas are still slight, they may prove as useful as they are elegant. The models are well described with several illuminating comments on each making otherwise fairly standard material well worth reading.

Two small complaints on an otherwise excellent book. The first is the virtual omission of cosmic ray results. While it is true that most accelerator physicists seem to view this as most psychologists view parapsychology, one has the feeling that it could be useful to have some account of its indications for the future. Perhaps this is ultra high energy physics, however. The very brief mention of high transverse momentum processes also seem not to reflect its likely future interest and is surprising in view of Horn's major contributions to it. These omissions apart, the book gives a most readable and critical account of the problems and prospects in very high energy physics.

D. G Sutherland

Gravitation

By C. W. Misner, K. S. Thorne and J. A. Wheeler. *pp. xxvi+1279. W. H. Freeman, London: 1973. £19.20 cloth, £8.60 paper.*

With the exception of quantum mechanics, the great theories of physics were not accepted immediately. Many years elapsed before the 'theoretical-physicist-in-the-street' became familiar with their basic ideas, or the texture of their mathematical formalism. Eventual acceptance of each theory was signalled by an explosion of research papers exploring its details, and culminated in the appearance of the 'classic text'—a high-level pedagogic work containing the foundations and formalism of the theory, together with a rich selection of applications. For example, Fowler's *Statistical Mechanics* appeared in 1929, fifty years after the pioneering work of Boltzmann and Gibbs.

In a similar way, this massive textbook on *Gravitation* marks the coming-of-age, after nearly sixty years, of Einstein's general theory of relativity. Why is it that the last decade has seen such a dramatic intensification of research in this subject? There are three reasons: First, for today's mathematical physicist, increasingly familiar with group theory, abstract algebra, topology and other mathematical esoterica, the tensor calculus employed in Einstein's theory is no longer intimidating. Second, the absence of a comprehensive theory of elementary particles had led many physicists to re-examine gravitation, in the hope that it might provide the 'missing link' in a general theory of matter. Third, the march of technology has caught up with Einstein, and many of the predictions of his theory are now being subjected to detailed experimental test.

In this book great emphasis is laid on the geometric interpretation of general relativity. The basic idea of the theory can then be stated very simply: 'geometry tells matter how to move, and matter tells geometry how to curve'. As a description of the gravitational effect of one body on another this is as different as it is possible to imagine from the Newtonian view. Newton says 'space and time are absolute. Spacetime is the passive arena of events. Gravitation is an inverse-square law force between pairs of bodies, proportional to the product of their masses. The acceleration of each body is the force on it, divided by its mass'. Einstein says 'spacetime is not absolute; its decomposition into space and time is different for different observers. Moreover, spacetime is anything but passive; it is curved, and the paths of particles and light rays are 'straightest lines' (geodesics), like the great circles on the surface of a sphere. Each body contributes to the spacetime curvature determining its motion and that of all other bodies'. Despite this great difference in conceptual foundation, the predictions of the two theories are virtually identical in all the usual applications to celestial mechanics, astronautics, engineering, etc.—in fact Newton's theory appears as a special case of Einstein's, when gravitational fields are weak and velocities small compared with that of light.

After a brief introduction, the authors introduce spacetime physics via special relativity, in which the masses of bodies are so small that spacetime can be regarded as flat. Then the main line of formal development begins, with two hundred pages devoted to 'the mathematics of curved space-time'. The novel feature here is the use of Cartan's 'absolute' notation for tensors and operations on tensor fields. This is a generalization of the coordinate-free notation for vectors (e.g. V for velocity) and for operators like grad, div and curl. The basic concepts of metric and curvature are thoroughly discussed, and enough examples are given to develop the facility in 'index gymnastics' necessary to anybody doing serious calculations in relativity.

In the next part of the book the physical content of general relativity—for which the authors employ the useful term 'geometrodynamics'—is stated. The curvature of spacetime is related to its matter content by Einstein's field equations, and the metric which describes spacetime and determines the geodesic motion of bodies is related to measurements with rods and clocks. Then follow detailed discussions of the Newtonian limit, 'elementary' dynamical quantities like mass and angular momentum, and conservation laws and variational principles. There is a beautifully clear chapter in which all of the non-quantum branches of physics are incorporated into general relativity; this is necessary, firstly because all of physics should hang together, and secondly because many applications of relativity are not 'pure', but involve thermodynamics, hydrodynamics, electrodynamics, geometrical optics or kinetic theory.

Now the applications begin, the first being to astrophysics. A hundred pages develop the equations governing matter inside stars, and detailed discussions are given of pulsars, neutron stars and spherical star clusters. To deal with the last case it is necessary to introduce relativistic orbit theory—that is, to study the geodesic motion of test particles and light rays in the curved spacetime surrounding a massive body. The discussion is very clear but it does seem a bit idiosyncratic to bury this important topic in a section on astrophysics.

The next major application is to cosmology, that is to the splendidly arrogant study of the universe as a whole.

Here the authors' 'purist' approach to Einstein's theory is strongly felt. There are various alternative relativistic theories of gravitation, which are more general and less simple than Einstein's. In one of these theories (due to Brans and Dicke), the metric field has a scalar as well as a tensor component. In another (due to Einstein but later rejected by him as 'the biggest blunder of my life') the curvature of spacetime is produced not only by matter but also by the so-called 'cosmological constant', which is a postulated additional fundamental constant of nature. The authors give full accounts of these theories, but devote overwhelming attention to the simplest 'pure Einstein' view. This includes the assumption that spacetime is *closed* for the universe as a whole (just as the two-dimensional surface of a sphere is closed) —an assumption necessary to avoid arbitrarily-selected 'boundary conditions at infinity'. The resulting cosmological model is unique: there are no arbitrary constants or boundary conditions. In the authors' words 'the universe starts with a big bang, expands to a maximum dimension, then recontracts and collapses: no more awe-inspiring prediction was ever made. It is preposterous. Einstein himself could not believe his own prediction. It took Hubble's observations (showing the expansion of the universe) to force him and the scientific community to abandon the concept of a universe that endures from everlasting to everlasting'. The experimental evidence favouring this view is considerable, and this book gives a useful account of it.

The third application is to gravitational collapse and black holes; the authors' treatment of these fashionable topics is the fullest yet published. We have mentioned the eventual collapse of the universe. It is also a consequence of general relativity, combined with the other laws of physics, that massive stars must also inevitably collapse, the pressure of matter and radiation being overwhelmed by the gravitational self-attraction. Before this collapse is complete, the star contracts through a radius of no return after which even light emitted by the star falls back onto its surface instead of radiating 'to infinity'. Seen from outside, it has become a 'black hole'. The laws of black-hole dynamics are presented here, and it is shown that only the mass, angular momentum and charge of a black hole can ever influence its surroundings; no other property can 'get out'. With the same whimsy that has enriched our language with the terms 'quark' and 'bootstrapping', this deep theorem has been stated as follows: 'A black hole has no hair'.

The fourth application is to gravitational waves. An accelerating mass (e.g. the earth orbiting the sun) should, according to general relativity, radiate gravitational waves, the mechanism being analogous to the radiation of electromagnetic waves by accelerated charges. The analogy is imperfect, however, because gravitational waves are *nonlinear*. It is easy to see this: gravitational waves are ripples of curvature in spacetime; they carry energy whose mass equivalent itself affects the curvature. This nonlinearity greatly complicates the mathematical description. However, a few exact solutions are known, and we are given a detailed discussion of them, and of various approximate treatments of gravitational wave propagation. Then the generation of gravitational waves is examined; the strongest sources are obviously likely to be astrophysical, and calculations are presented for the strength and nature of waves from collapsing stars matter falling into black holes, pulsars, supernovae and binary stars. But these waves are all so faint that none has yet been detected; we are on the forefront of technology, and an impressive range of ingenious mechanical detectors has been designed and built, all of which are discussed here. The next decades should see these problems solved, and if

Einstein's theory and astrophysics are even roughly correct we shall witness a revolution in the way we perceive the universe: as well as our sense of *sight*, augmented bv telescopes (optical and radio), we shall use our sense of *touch*, augmented by gravitational wave detectors—we shall be able to feel the pulse of the universe.

The fifth and final application deals with the experimental validation of Einstein's theory. As well as the three classic tests (bending and red shift of light in gravitational fields and precession of the perihehon of mercury), there are now several others (time delay in radar propagation, precession of gyroscopes, three-body effects and periodic perturbations of orbits), some of which have been carried out. Here the authors make a curious omission: they make no mention of the beautiful experiment of Hafele and Keating, who carried a clock around the world and then compared it with one that had remained at rest. The two clocks had measured different time intervals, and the difference agreed precisely with that predicted by general relativity. This experiment settles the long discussion of the 'clock paradox' conclusively in Einstein's favour: it is no more paradoxical for two clocks (or people) to experience different time intervals between meetings than it is for two strings with different lengths to join the same two points. The discussion in this book of the other experiments is thorough, and a particularly valuable aspect of it is a careful analysis of exactly which part of the theory is being tested in each case. It is stressed that the mass of evidence supporting Newton's theory can with equal justification be regarded as supporting general relativity. The upshot of all these experiments is very simple; after sixty years Einstein's theory is unshaken, while its competitors are either ruled out or increasingly implausible.

Now, after well over 10^3 pages, the final section begins. Called 'Frontiers', it is an attempt to examine the limitations of general relativity, and to glimpse the territory beyond. After two mathematical chapters, the authors expose the central problem: what happens at the end-point of gravitational collapse? According to general relativity, massive stars (and the universe itself) will collapse to a point. But theoretical physicists abhor singularities, and there lies the difficulty. The authors believe that this 'issue of the final state' is 'the greatest crisis in physics of all time'. What can soften the singularity? It appears that quantum effects provide the best hope. Normally, quantum mechanics and gravitation operate on utterly different scales, the former being totally negligible in celestial mechanics and the latter being totally negligible within the atom. In the unimaginably dense matter of a collapsing star, however, this need no longer be the case. How, then, to quantize general relativity? It is suggested that wave functions operate in 'superspace'; this is the (infinite dimensional) space of all possible curved three-dimensional spaces, the spacetimes of relativity being the histories of points moving about in superspace. These are indeed frontiers, as yet far removed from the possibility of experimental test. But tomorrow, who knows?

The book is beautifully presented, and incorporates at this most advanced level all the techniques of abundant illustration and clear and varied typography that make American elementary texts so attractive. There is a bibliography over thirty pages long, and the end papers give an analysis of the confusing variety of sign conventions in current use, and lists of useful numbers. The text contains a wealth of quotations and historical perspectives.

It is intended that the book should supply two routes through its subject, an elementary route called track one, and an advanced route called track two, which resembles the passages in small print in older texts, except that most of the book is in fact track two. I found this division unhelpful; much of track one is more difficult than much of track two, and the assignment of material often seems arbitrary. The entire book 'is designed for a rigorous, full-year course at the graduate level'. This is very optimistic; although the book is a delight to dip into, it is very difficult to work through—not, I hasten to add, because of obscurity of presentation, but because of the sheer intellectual weight of the subject.

On any broad view, however, these are minor criticisms, for this is one of the great books of science, a lamp to illuminate this Aladdin's cave of theoretical physics whose genie was Albert Einstein. All science libraries, all relativists, all cosmologists, must buy it, all theoretical physicists should read it, all scientists should at least dip into it.

MICHAEL BERRY

Semiconductor physics

By KARLHEINZ SEEGER. *pp. xv+514. Berlin: Springer, 1973. £9.40.*

This is a refreshing book. It provides a clear account of semiconductor physics with particular emphasis on developments in the last decade. The number of topics covered is vast. No doubt somebody's pet topic has been ignored. If you have never been interested in magnetic freeze out, the magnetophonon effect, the Gunn effect, magneto-optical phenomena, nonlinear optical effects, acoustoelectric effects, surface transport, superconducting semiconductors, amorphous semiconductors, organic semiconductors and so on, then you may not like Professor Seeger's book. In that case presumably you do not like semi-conductor physics either and should turn to another review. Readers with research activities in the semiconductor field will find that Professor Seeger has something interesting to say about a great many phenomena which have been in the news recently. In addition he provides good coverage of the traditional aspects of semiconductor physics. Of necessity, the treatment of special modern topics is sometimes brief but it is always interesting and lucid. Good references for further reading are given which are fairly complete up to 1970 with one or two in later years.

The style and judgement of the author are what makes the book refreshing. Professor Seeger has chosen to do his mathematics in some detail. When that would prove to be too tedious he gives a reference. What goes out in order to make room for the mathematical detail is exhaustive accounts of the properties of particular materials. The result is a pleasure to read. The book has been set on an IBM 72 composer with one disconcerting result to which the author draws attention in his preface. The letter l is really only disginguishable from the number one by the context. Some of the formulae look a little odd until one adjusts. This is, however, a trifling matter in an otherwise excellent typography.

The first four chapters provide an introduction to band theory, electron statistics and transport phenomena. The emphasis is on semiconductors, of course, and most British undergraduates would be taught this material from a broader viewpoint. Chapter 5 deals with junctions and transistors. Scattering processes in a single spherical valley, in multivalley situations and in the warped sphere model occupy the next three chapters. This is first class material for first year postgraduate students specializing in semiconductor physics whether they be experimentalists or theoreticians. The author has not included any problems for solution by the students. At the postgraduate level this is an advantage. The absence of problems will remove the guilt feelings from students who never do them anyway. All the important