

# Contents

<b>chapter 1</b>	<b>Definition and History</b>	<b>1</b>
1.1	Definition, 1	
1.2	History, 2	
<b>chapter 2</b>	<b>Infrared Sources</b>	<b>11</b>
2.1	Definition of Terms, 12	
2.2	Emission from Heated Bodies, 13	
2.2.1	<i>Kirchhoff's law</i> , 14	
2.2.2	<i>The Stefan-Boltzmann law</i> , 15	
2.3	Wavelength Distribution, 20	
2.3.1	<i>The Rayleigh-Jeans expression</i> , 20	
2.3.2	<i>The Planck radiation formula</i> , 24	
2.3.3	<i>The Wien displacement law</i> , 29	
2.4	The Exchange of Radiant Power between Two Bodies, 38	
2.4.1	<i>The geometrical effects</i> , 38	
2.4.2	<i>The goniometric emitting and absorbing characteristics of surfaces</i> , 42	
2.4.3	<i>Examples</i> , 48	
2.5	Time Distribution, 53	
2.5.1	<i>Coherence</i> , 54	
2.5.2	<i>Power fluctuations due to the rate at which photons are emitted by a source</i> , 57	
2.5.3	<i>Fluctuations in number of photons</i> , 59	
2.6	Line and Band Sources—Introduction, 60	
2.6.1	<i>Stationary states and line spectra</i> , 61	
2.6.2	<i>Matter waves and wave mechanics</i> , 62	
2.6.3	<i>Vibration-rotation spectra</i> , 63	

2.6.4	<i>Polyatomic molecules</i> , 66	
2.6.5	<i>Normal modes and normal coordinates</i> , 67	
2.6.6	<i>Line breadth</i> , 69	
2.7	Practical Sources, 71	
2.8	Sources Encountered outside the Laboratory, 75	
2.9	Other Sources, 78	
2.10	Useful Approximations for Engineering Calculations, 84	
<b>chapter 3</b>	<b>The Theory of the Infrared Optical Characteristics of Media</b>	<b>87</b>
3.1	Introduction and General Discussion, 87	
3.2	Electromagnetic Theory, 88	
3.2.1	<i>Maxwell's equations</i> , 88	
3.2.2	<i>The wave equations and optical constants</i> , 90	
3.3	Electromagnetic Power Flow, 95	
3.4	Media Discontinuities, 96	
3.4.1	<i>Boundary conditions</i> , 97	
3.4.2	<i>Refraction and Snell's law</i> , 98	
3.4.3	<i>Reflection</i> , 98	
3.5	Absorption, Dispersion and, Scattering, 101	
3.5.1	<i>Absorption and dispersion</i> , 102	
3.5.2	<i>Scattering</i> , 107	
3.6	Interference and Diffraction, 109	
3.6.1	<i>Interference</i> , 110	
3.6.2	<i>Diffraction</i> , 112	
<b>chapter 4</b>	<b>Optical Properties of Media</b>	<b>119</b>
4.1	Introduction, 119	
4.2	Class of Matter—Their Optical Properties, 119	
4.2.1	<i>Solids</i> , 119	
4.2.2	<i>Liquids</i> , 127	
4.2.3	<i>Gases</i> , 128	
4.3	Choice of Specific Materials, 128	
4.3.1	<i>Requirements for windows</i> , 128	
4.3.2	<i>Requirements for domes</i> , 129	
4.3.3	<i>Other optical components</i> , 131	
4.3.4	<i>Available materials</i> , 138	
<b>chapter 5</b>	<b>Optical Properties of the Atmosphere</b>	<b>162</b>
5.1	Introduction, 162	
5.2	Description of the Atmosphere, 163	
5.3	Molecular Absorption—Theory, 167	
5.4	Molecular Absorption—Empirical Discussion, 172	

5.5	Scattering by the Atmosphere—Theory, 181	
5.5.1	<i>Geometrical optics approach</i> , 183	
5.5.2	<i>Electromagnetic theory approach—Mie’s theory</i> , 186	
5.6	Scattering by the Atmosphere—Empirical Discussion, 189	
<b>chapter 6</b>	<b>The Physics of Semiconductors</b>	<b>194</b>
6.1	Introduction, 194	
6.2	The Periodic Lattice, 194	
6.3	Energy Bands in a Perfect Crystal, 197	
6.4	Imperfections in the Lattice, 200	
6.5	Fermi-Dirac Statistics for an Intrinsic Semiconductor, 204	
6.6	Fermi-Dirac Statistics for an Extrinsic Semiconductor, 208	
6.7	Electrical Conductivity and the Hall Effect, 210	
6.8	Recombination and Lifetime, 219	
6.9	Motion of Carriers in the Presence of Electric and Magnetic Fields, 222	
6.10	Rectifying Junctions, 228	
<b>chapter 7</b>	<b>Sources of Noise</b>	<b>235</b>
7.1	Introduction, 235	
7.2	Thermal Noise—Nyquist Theorem, 236	
7.3	Noise in Electron Tubes, 241	
7.3.1	<i>Shot noise in saturated and exponential diodes</i> , 242	
7.3.2	<i>Shot noise in space charge limited diodes</i> , 246	
7.3.3	<i>Shot noise in triodes</i> , 247	
7.3.4	<i>Partition noise</i> , 249	
7.3.5	<i>Flicker noise</i> , 249	
7.3.6	<i>Microphonics</i> , 249	
7.3.7	<i>Noise resistances of selected receiving tubes</i> , 251	
7.4	Noise in Semiconductors, 251	
7.4.1	<i>Current noise</i> , 253	
7.4.2	<i>Generation-recombination noise</i> , 255	
7.5	Noise in Transistors and Diodes, 258	
7.6	Noise in Transformers, 260	
7.7	Noise in Galvanometers, 261	
<b>chapter 8</b>	<b>Phenomenological Description of Infrared Detection Mechanisms</b>	<b>265</b>
8.1	The Infrared Detector, 265	
8.2	Figures of Merit, 268	
8.3	Photon Effects, 277	
8.3.1	<i>Photoemissive effect</i> , 277	
8.3.2	<i>Photoconductivity</i> , 288	
8.3.3	<i>Photovoltaic effect</i> , 296	
8.3.4	<i>Photoelectromagnetic effect</i> , 299	

8.3.5	<i>Dember effect</i> , 300	
8.3.6	<i>Filterscan tube</i> , 301	
8.3.7	<i>Phosphors</i> , 302	
8.3.8	<i>Microwave effects</i> , 305	
8.3.9	<i>Narrow band quantum counters</i> , 306	
8.3.10	<i>Photographic film</i> , 308	
8.4	Thermal Effects, 308	
8.4.1	<i>Metal and thermistor bolometers</i> , 309	
8.4.2	<i>Superconducting bolometer</i> , 312	
8.4.3	<i>Thermocouple and thermopile</i> , 313	
8.4.4	<i>Golay cell</i> , 314	
8.4.5	<i>Evaporograph</i> , 315	
8.4.6	<i>Absorption edge image converter</i> , 316	
<b>chapter 9</b>	<b>Mathematical Analyses of Selected Detection Mechanisms and of the Photon Noise Limit</b>	<b>321</b>
9.1	Introduction, 321	
9.2	Noise in Detectors, 322	
9.3	Mathematical Theory of Selected Detection Mechanisms, 324	
9.3.1	<i>Photoconductivity</i> , 327	
9.3.2	<i>Photoelectromagnetic effect</i> , 333	
9.3.3	<i>Photovoltaic effect</i> , 337	
9.3.4	<i>Bolometer</i> , 345	
9.4	Theoretical Performance of Photon Noise Limited Detectors, 349	
9.4.1	<i>Photon noise limitations of thermal detectors</i> , 351	
9.4.2	<i>Temperature noise in thermal detectors</i> , 354	
9.4.3	<i>Photon noise limitations of photon detectors</i> , 356	
9.4.4	<i>Photon noise limit of a narrow band quantum counter</i> , 371	
9.4.5	<i>Signal fluctuation limit</i> , 376	
9.5	Means of Achieving Photon Noise Limited Performance, 377	
	Appendix I. Determination of $D_{\lambda}^*(\lambda, f, \Delta f)$ from $D^*(T, f, \Delta f)$ 384	
	Appendix II. Havens' Limit, 385	
<b>chapter 10</b>	<b>Comparative Performance of Elemental Detectors</b>	<b>386</b>
10.1	Introduction, 386	
10.2	Some General Remarks Concerning Elemental Photon Detectors, 389	
10.2.1	<i>Comparison of thin film and single crystal detectors</i> , 389	
10.2.2	<i>Comparison of extrinsic and intrinsic materials</i> , 390	
10.2.3	<i>Detector impedance</i> , 391	
10.2.4	<i>Size and shape of sensitive area</i> , 392	

10.2.5	<i>Temperature of operation</i> , 393	
10.2.6	<i>Photocell housings</i> , 393	
10.2.7	<i>Infrared transmitting windows and immersion optics</i> , 398	
10.3	The Lead Salt Photoconductors, 399	
10.3.1	<i>Lead sulfide (PbS)</i> , 399	
10.3.2	<i>Lead selenide (PbSe)</i> , 402	
10.3.3	<i>Lead telluride (PbTe)</i> , 403	
10.4	Germanium, 404	
10.4.1	<i>Gold-doped germanium (Ge:Au), p-type</i> , 404	
10.4.2	<i>Gold, antimony-doped (Ge:Au,Sb), n-type</i> , 405	
10.4.3	<i>Zinc-doped germanium (Ge:Zn), "Zip"</i> , 406	
10.4.4	<i>Zinc, antimony-doped (Ge:Zn,Sb)</i> , 407	
10.4.5	<i>Copper-doped germanium (Ge:Cu)</i> , 407	
10.4.6	<i>Cadmium-doped germanium (Ce:Cd)</i> , 407	
10.4.7	<i>Germanium-silicon alloys (Ge-Si:Au;Ge-Si:Zn,Sb)</i> , 408	
10.5	Indium Antimonide (InSb), 409	
10.5.1	<i>Photoconductive mode</i> , 409	
10.5.2	<i>Photovoltaic mode</i> , 410	
10.5.3	<i>Photoelectromagnetic mode</i> , 411	
10.6	Indium Arsenide (InAs), 411	
10.7	Tellurium (Te), 412	
10.8	Thallosulfide (Tl <sub>2</sub> S), 412	
10.9	Mercury Telluride-Cadmium Telluride (HgTe-CdTe), 413	
10.10	Thermistor Bolometer, 414	
10.11	Superconducting Bolometer, 414	
10.12	Carbon Bolometer, 415	
10.13	Radiation Thermocouple, 416	
10.14	Golay Cell, 416	
10.15	Detectors for the Visible Spectrum, 417	
10.15.1	<i>Cadmium sulfide (CdS)</i> , 417	
10.15.2	<i>Cadmium selenide (CdSe)</i> , 418	
10.15.3	<i>Selenium-selenium oxide (Se-SeO)</i> , 418	
10.15.4	<i>Gallium arsenide (GaAs)</i> , 418	
10.15.5	<i>1N2175 silicon photo-duo-diode</i> , 418	
10.15.6	<i>1P21 photomultiplier</i> , 419	
<b>Some Useful Engineering Approximations</b>		<b>436</b>
Appendix I. Ratio of $D_{\lambda_p}(\lambda_p, f, \Delta f)$ to $D^*(500^\circ \text{K}, f, \Delta f)$ for Selected Detectors		
Appendix II. Approximate Method for Converting the Value of $D^*(T_1, f, \Delta f)$ to $D^*(T_2, f, \Delta f)$		
Appendix III. Useful Frequency Range of a Detector		
<b>Index</b>		<b>439</b>