

## Index

### **symbols**

- 20 *Aql* 49
- 21 μm feature 106, 137, 138, 141, 149, 188
- 3.4 μm feature 84, 86, 92, 94, 104, 118, 120, 122, 153, 154, 160, 161–166, 187
- 30 μm feature 106, 137, 138, 141, 188
- 220 nm feature 84, 162, 188
- 1,3-dihydroxyacetone, DHA 65
- IDP L2011\*B2* 120

### **a**

- abiological theory of oil 155
- abiotic synthesis 1
- acetaldehyde ( $\text{CH}_3\text{CHO}$ ) 1, 31, 32, 56, 122
- acetamide ( $\text{CH}_3\text{CONH}_2$ ) 40, 166
- acetic acid ( $\text{CH}_3\text{COOH}$ ) 30, 63
- acetone ( $\text{CH}_3\text{COCH}_3$ ) 33, 34
- acetonitrile ( $\text{CH}_3\text{C}\equiv\text{N}$ ) 35
- acetylene ( $\text{C}_2\text{H}_2$ )
  - 11, 12, 29, 106, 107, 114, 150, 169
  - acetylene addition 169
  - acetylene derivative 32
- adenine 21, 22, 65, 157, 174, 179
- adenosine triphosphates (ATP) 57
- AFGL 2688* 68, 73, 75, 141
- AFGL 3068* 73, 75
- AFGL 618* 74, 107, 169
- AFGL sky survey 101
- alanine 20, 157, 168
- albedo 115, 123, 145
- $\text{AlCl}$  61
- alcohols 2, 11, 12, 29, 30, 35
- aldehydes 11, 12, 31, 65, 116
- aldoses 65
- $\text{AlF}$  61
- algae 112
- aliphatics 12, 84
- alkanes 12, 28, 105, 153, 155
- alkenes 12, 29, 105, 155
- alkyl group 12, 34
- alkynes 12, 29
- Allende* meteorite 118
- amides 35, 166
- amino acids 6, 19, 20, 35, 63, 65, 116, 157, 165–167, 174, 178
- ammonia ( $\text{NH}_3$ ) 6, 12, 35, 36, 113, 125, 157, 166–168, 178
- amorphous carbon 144, 160
- amorphous silicates 90, 99, 144, 145, 160
- amorphous state 145
- amphiphiles 168
- Antarctica 182
- anthracite 18, 135
- antimaser 32
- antisymmetric stretch 25, 49
- Apache Point Observatory 132
- arachidic acid 19
- archaea 175
- Arecibo Observatory 72
- Arizona Radio Observatory (ARO) 73
- aromatic infrared bands (AIB) 9, 85, 89–91, 129, 138, 187
- aromatics 12
- aromatization 169
- asteroids 123, 159, 160, 183, 188
- astrochemistry 7, 127, 165, 186
- astromineralogy 145
- asymmetric rotator 32–34
- asymptotic giant branch (AGB) stars 3, 29, 62, 69, 97, 101, 183, 188
- atmosphere 112
- Australian Telescope Compact Array (ATCA) 64
- autoexhaust 149

**b**

bacteria 112, 153, 160, 174, 175  
 bandgap 145, 146  
 $BD+30^{\circ} 3639$  100  
 Bell Labs 7-m telescope 72  
 bending modes 9, 25, 28, 29, 37, 44, 49, 58  
 benzene ( $C_6H_6$ )  
     11, 12, 29, 52, 107, 114, 150, 169  
 Berkeley–Illinois–Maryland Array (BIMA)  
     31, 72  
 $\beta$  decay 3  
 Big Bang 3, 187  
 biochemistry 2  
 bioluminescence 162  
 biomass 113  
 biosphere 113, 189  
 biotin 65  
 bituminous coal 18  
 blue luminescence 136  
 butane ( $C_4H_{10}$ ) 153, 154  
 butatriene ( $H_2C=C=C=CH_2$ ) 16  
 butatrienyldiene ( $H_2CCCC$ ) 45, 47

**c**

$c\text{-}C_3H$  45, 53  
 $C_2$  24, 97, 146  
 $C_2H_4$  114  
 $C_2H_6$  114  
 $C_3$  24, 49, 97, 146, 174  
 $C_3H$  46  
 $C_3H_4$  114  
 $C_3H_8$  114  
 $C_4$  49  
 $C_5$  49, 146, 174  
 $C_6$  49  
 $C_{60}$  68, 69, 128  
 $C_6H$  45  
 calcium monocarbide ( $CaC$ ) 63  
*Callisto* 109, 115  
 Caltech Submillimeter Telescope (CSO)  
     71, 73  
 candle flame 18  
 carbenes 16, 45  
 carbohydrates 6, 19, 63  
 carbon black 18, 150  
 carbon chains 16, 133, 146  
 carbon clusters 168  
 carbon nanoparticles 151  
 carbon onions 69, 135, 136  
 carbon stars 17, 29, 49, 97, 168, 187  
 carbonaceous chondrites 169, 183  
 carbonyl 11  
 carboxylic acid derivatives 35

carboxylic acids 30, 116  
 carbynes 13, 16, 45  
 Cassini–Huygens 114, 115  
 CAW 168  
 CCCH 45, 52  
 CCH 45, 75  
 cellulose 19, 160  
 centrifugal distortion 50  
 $CH$  6, 24, 41  
 $CH^+$  6, 24, 41, 75  
 $CH_2D^+$  44  
 $CH_3$  44  
 $CH_3C_3N$  52  
 $CH_3H^+$  48  
 $CH_3N^-$  48  
 $CH_4H^+$  48  
 $CH_{60}^+$  68  
 $CH_6H^+$  48  
 $CH_8H^+$  48  
 Chandra Observatory 190  
*Charon* 115  
 chemical pathway 170  
 chemical vapor deposition 13, 67  
 $\chi$  *Oph* 7  
 Chicxulub 180  
 chiral molecules 65  
 chlorophyll 65, 162  
 chromatography 110  
 chromophore 163  
 chrysene ( $C_{18}H_{12}$ ) 58  
 cinnoline 162  
 circumstellar envelopes  
     17, 37, 46, 48, 58, 61, 62, 100, 168, 169, 188  
*CIT* 6 73, 75  
 $CN$  6, 7, 24, 41, 97  
 $CN^-$  48  
 $CO$  75  
 $CO_2$  25  
 coal  
     13, 18, 106, 113, 153, 154, 156, 157, 185, 189  
 coalescence 18  
 combustion 17, 18, 149, 150, 169  
*Comet 81P/Wild 2* 122  
*Comet Hale-Bopp* 122  
*Comet Halley* 122  
*Comet Hyakutake* 122  
 comets 120, 182, 183, 186, 188  
 conduction bands 146  
 conformers 30, 34, 63, 77  
 Copernican revolution 177  
 Copernicus satellite 84  
 corannulene 148  
 coronene ( $C_{24}H_{12}$ ) 58, 135

- corundum 183  
 cosmic abundance 5  
 cosmic background radiation 32  
 CP 57  
 craters 180  
 Cretaceous-Tertiary boundary 180  
 crude oil 153, 154  
 crystalline silicates 145  
 crystalline state 145  
 cumulene carbenes 45  
 cumulenes 16  
*CY CMa* 72  
 cyanamide ( $\text{NH}_2\text{CN}$ ) 38  
 cyanides 62, 159  
 cyanoacetylene ( $\text{HCCCN}$ ) 47, 50  
 cyanoallene ( $\text{CH}_2\text{CCHCN}$ ) 51  
 cyanoformaldehyde ( $\text{CNCHO}$ ) 32  
 cyanopolynes 14, 16, 29, 45, 46, 81, 174  
 cycloalkanes 153, 154  
 cyclopropane ( $\text{C}_3\text{H}_6$ ) 52  
 cyclopropenone ( $c\text{-H}_2\text{C}_3\text{O}$ ) 55  
 cyclopropenylidene ( $\text{C}_3\text{H}_2$ ) 53, 54, 149  
 cyclopropynylidyne ( $c\text{-C}_3\text{H}$ ) 52  
 cytosine 21, 22, 65
- d**  
 $\text{D}_2\text{O}$  72  
 dark clouds 79, 136  
 Darwinian revolution 177, 178  
 deformation modes 149, 166  
 deoxyribose 65  
 deuterium 44, 120, 122  
 diacetylene ( $\text{C}_4\text{H}_2$ ) 29, 107, 114, 169  
 diamantane 14  
 diamondoids 14  
 diamonds  
     67, 112, 135, 137, 144, 145, 168, 183  
 diffuse interstellar bands (DIB)  
     15, 68, 130, 146, 186, 188  
 dimethyl carbonate [ $(\text{CH}_3\text{O})_2\text{CO}$ ] 65  
 dimethyl ether ( $\text{CH}_3\text{OCH}_3$ ) 34, 35, 71  
 dipole moment  
     35, 37, 42, 44, 45, 49, 58, 63, 148  
 dissociative recombination 165  
 distillate aromatic extracts (DAE) 157  
 DNA 21, 22, 65, 175  
 Doppler effect 7  
 dust 99, 160, 171
- e**  
*E. coli* 160  
*Earth* 109, 112, 177, 180  
 Earth's mantle 155  
 Effelsberg Telescope 31
- electric-dipole transitions 32  
 electron diffraction 67  
 elemental depletion 61, 63  
*Elias 1* 67  
 emission nebulae 79  
 emission plateaus 105  
*Enceladus* 114  
 enols 29  
 enzymes 2, 61, 175  
 esters 34, 35  
 ethane ( $\text{C}_2\text{H}_6$ ) 12, 28, 44, 114, 116, 153, 154  
 ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ) 30, 166  
 ethanolamine 168  
 ethers 11, 34  
 ethinylisocyanide ( $\text{HCCNC}$ ) 47  
 ethyl acetate ( $\text{CH}_3\text{COOCH}_2\text{CH}_3$ ) 34  
 ethyl cyanide ( $\text{CH}_3\text{CH}_2\text{CN}$ ) 63  
 ethyl methyl ether ( $\text{CH}_3\text{OC}_2\text{H}_5$ ) 34  
 ethylamine ( $\text{CH}_3\text{CH}_2\text{NH}_2$ ) 35  
 ethylene ( $\text{H}_2\text{C}=\text{CH}_2$ ) 11, 12, 29, 150  
 ethylene glycol ( $\text{HOCH}_2\text{CH}_2\text{OH}$ ) 30, 122  
 ethylene oxide ( $c\text{-C}_2\text{H}_4\text{O}$ ) 55, 56, 148, 149  
 eukaryotes 175  
*Europa* 109, 160  
 extended red emission (ERE)  
     87, 93, 95, 136, 149, 188  
 extinction 99  
 extinction curve 135, 143  
 extrasolar planets 125, 177  
 extraterrestrial life 20
- f**  
 fat 19  
 fatty acids 19  
 fermentation 2  
 filmy QCC 152  
 fine structure 28, 45  
 fine-structure lines 43, 44, 63  
 flame 150  
 fluorene 58, 61  
 fluorescence 147  
 fluorescent protein 163  
 formaldehyde ( $\text{H}_2\text{CO}$ ) 31, 45, 71, 166, 175  
 formamide ( $\text{NH}_2\text{CHO}$ ) 38, 39  
 formic acid ( $\text{HCOOH}$ ) 31, 39  
 formose reaction 175  
 fossil fuel 155  
 fossils 56  
 fructose 19  
 fullerenes 14  
 fullerene onions 15  
 fullerenes 14, 68, 118, 133, 140, 149, 151, 168  
 functional groups 11, 12, 25, 157, 159  
 fungal spores 160

- furan ( $C_4H_4O$ ) 65, 66  
*FY<sub>9</sub>* 124
- g**  
*G31.41+0.31* 64  
*G327.3-0.6* 72  
 Galactic Center 54  
 galaxies 131, 136, 187  
 Galileo Entry Probe 114  
 Galileo Orbiter 114  
*Ganymede* 109, 115  
 gas chromatography-mass spectrometry (GCMS) 111, 157  
*GCS3* 84, 85  
 Gemini 124  
 giant molecular clouds 81  
 giant planets 56  
 glucose 19  
 glyceraldehyde ( $CH_2OHCHOHCHO$ ) 65, 175  
 glyceric acid 168  
 glycerol 168  
 glycine ( $NH_2CH_2COOH$ ) 20, 30, 37, 40, 63, 157, 168  
 glycolaldehyde ( $CH_2OHCHO$ ) 64, 175  
 graphene sheets 13, 15, 18  
 graphite 13, 18, 112, 135, 144, 146, 149, 160, 161, 168  
 Green Bank Telescope (GBT) 32, 40, 64  
 green fluorescent protein 163  
 Greenland 182  
 guanine 21, 22  
 guanosine triphosphates (GTP) 57
- h**  
*H<sub>2</sub>* 27  
*H<sub>2</sub>Cl<sup>+</sup>* 72  
*H<sub>2</sub>CO* 6  
*H<sub>2</sub>O<sup>+</sup>* 72  
 HII regions 7, 54, 136  
 halides 62  
 haze 114, 115, 186  
*HC<sub>11</sub>N* 46, 48  
*HC<sub>3</sub>N* 6, 29, 174  
*HC<sub>5</sub>N* 29  
*HCCNC* 47  
*HCN* 6, 28, 29, 36, 37, 75, 115, 157, 174, 179  
*HCN* polymer 157–159, 162, 183  
*HCO<sup>+</sup>* 74, 75  
*HCP* 57  
*HD 154368* 44  
*HD 189733b* 125  
*HD 44179 (the Red Rectangle)* 7, 41, 129, 136  
*HD 97048* 67
- hemoglobin 61, 65  
 Herbig Ae/Be stars 67  
 Herschel Space Observatory 42, 49, 72, 75  
 heterocyclic amines 35  
 heterocyclic aromatic compounds 147  
 heterocyclic compounds 65, 116  
 hexa-peri-hexabenzocoronene ( $C_{42}H_{18}$ ) 135  
 high resolution transmission electron microscopy (HRTEM) 151, 159  
 histamine 65  
 histidine 65  
 HMT 166  
 HNC 75  
 HNCCC 47  
 hot cores 34, 81  
*HR 4049* 129  
 HST GHRS 44  
 hybridization 11, 13, 18, 34  
 hydrazine ( $N_2H_4$ ) 12  
 hydrocarbons 12, 18, 116, 126, 150, 154, 155  
 hydrogen isocyanide (HNC) 71  
 hydrogen peroxide ( $H_2O_2$ ) 12  
 hydrogenated amorphous carbon (HAC) 94, 136, 137, 140, 149, 150  
 hydrogenated diamond 67  
 hydrogron abstraction 169  
 hydrostatic equilibrium 5  
 hydroxyl (OH) group 29  
 hyperfine lines 39, 45  
 hyperfine transitions 28, 35, 37, 39, 41, 42, 44, 51, 52, 62  
*Hyperion* 115
- i**  
*Iapetus* 115  
*IC 418* 141  
*IC 694* 93  
 ices 109, 122, 144  
*IDP L2008X3* 162  
*imidazole* ( $C_3H_4N_2$ ) 35, 65, 66  
 impact craters 180, 181  
 infrared cirrus 87  
 infrared excess 3  
 Infrared Radiometer Interferometer and Spectrometer (IRIS) 114  
*Innisfree meteorite* 181  
 insoluble organic matter (IOM) 117, 118, 120, 122, 126, 165, 166, 183, 186  
 insulin 61  
 interferometers 31  
 International Ultraviolet Explorer (IUE) 135  
 interplanetary dust particles (IDP) 118–121, 126, 159, 162, 182, 183, 186, 188

- inversion transitions 35  
*Io* 109  
 ion molecule reactions 165  
 Ion Neutral Mass Spectrometer (INMS) 114  
 IRAM 64  
 IRAM 30-m telescope 33, 34, 40  
 IRAM Plateau de Bure Interferometer (PdBI)  
 5, 64  
 IRAS 76, 84, 85, 87, 99, 101  
*IRAS 01005+7910* 69, 132  
*IRAS 04296+3429* 140, 141  
*IRAS 04396+3429* 154  
*IRAS 05113+1347* 138  
*IRAS 05341+0852* 138  
*IRAS 06530-0213* 138, 141  
*IRAS 07134+1005* 103, 105, 137, 141  
*IRAS 07430+1115* 138  
*IRAS 08572+3915* 92, 94  
*IRAS 21282+5050* 103–105, 129  
*IRAS 21318+5631* 98, 99, 106  
*IRAS 22272+5435* 104, 156, 157  
*IRAS 22574+6609* 138  
*IRAS 23304+6147* 138, 141  
*IRAS F00183-7111* 94  
 IRAS LRS 76  
*IRC+10216* 29, 45, 62, 68, 71–73, 141  
 IRTF 29, 122  
 IRTS satellite 76, 85, 86  
 ISO 29, 44, 49, 81, 101, 114, 186  
 ISO LWS 4, 42, 91, 138  
 ISO SWS  
 9, 82, 85, 91, 103, 104, 106, 107, 137, 138  
 ISOCAM 83  
 isocyanide 161  
 isocyanopolynes 45  
 isomers 14, 30, 31, 40, 45, 47, 52, 56
- j*  
 James–Clerk–Maxwell Telescope (JCMT)  
 71, 73  
 Jovian planets 109, 155  
*Jupiter* 109, 113
- k*  
 K-doublet 31, 32  
*K3-54* 69  
 KCl 61  
 Keck Telescope 122, 124  
 kerogen  
 13, 112, 113, 117, 121, 123, 153, 157, 166, 183, 186,~~189~~ 28, 44, 112–114, 116, 125, 152–155  
 ketene 32, 33  
 ketenimine 40  
 ketones 11, 12, 30, 31, 65, 116, 166  
 ketoses 65
- Kitt Peak 12-m Telescope 64  
 Kuiper Airborne Observatory (KAO)  
 36, 41, 49, 140, 186  
 Kuiper Belt 123  
 Kuiper Belt Objects (KBO) 123, 160
- l*  
*l-C<sub>3</sub>H* 45  
*l*-type doubling 37  
*L1152* 37  
*L134N* 32  
*A* doublet 6, 41  
*A* doubling 45  
 laser ablation 146, 149, 150  
 laser-induced pyrolysis 150  
 Last Universal Common Ancestor  
 (LUCA) 175  
 Late Heavy Bombardment 182  
 lattice vibrations 145  
 lauric acid 19  
 leucine 20  
 life 109, 175, 177  
 lignite 18  
 line confusion 77  
 lipids 19, 63, 153, 168, 174  
 local thermodynamical equilibrium (LTE) 51  
*Lost City* meteorite 181  
 lysine 20
- m*  
*M 1-12* 69  
*M 1-20* 69  
*M 82* 91, 95  
 Magellanic Clouds 91, 92, 131, 140, 141  
 main asteroid belt 181  
 main sequence 3  
 maria 180  
*Mars* 109, 181  
 mass loss 97, 100, 188  
 mass loss rate 188  
 mass spectrometry 110  
*Mercury* 109, 181  
 metal carbides 62  
 metal hydrides 62  
 meteor showers 182  
 meteorites 5, 67, 118, 126, 159, 165, 186, 188  
 meteoroids 118  
 meteors 118  
 methane (CH<sub>4</sub>)  
 12, 29, 32–34, 40, 84, 166  
 methyl cyanide (CH<sub>3</sub>CN) 40, 50, 71

- methyl formate ( $\text{CH}_3\text{OCHO}$ ) 31, 34, 35, 122  
 methyl glycolate ( $\text{CH}_3\text{OCOCH}_2\text{OH}$ ) 65  
 methylacetylene ( $\text{CH}_3\text{C}\equiv\text{CH}$ ) 50  
 methylamine ( $\text{CH}_3\text{NH}_2$ ) 35, 36, 38  
 methylcyanoacetylene ( $\text{CH}_3\text{C}_3\text{N}$ ) 51  
 methylcyanodiacetylene 51  
 methylcyanopolynes 45, 50, 81  
 methyldiacetylene ( $\text{CH}_3\text{C}_4\text{H}$ ) 50  
 methylene ( $-\text{CH}_2$ ) group 84, 166  
 methylene ( $\text{CH}_2$ ) 42, 43  
 methyleneamine ( $\text{CH}_2\text{NH}$ ) 37  
 methylpolynes 45, 50  
 methyltriacetylene ( $\text{CH}_3\text{C}_6\text{H}$ ) 50  
 $\text{MgCN}$  61  
 $\text{MgNC}$  61  
 $\text{MgS}$  141  
 micrometeorites 109, 182  
 micrometeoroids 118  
 microscope-based Fourier transform infrared ( $\mu\text{-FTIR}$ ) spectroscopy 111  
 Miller–Urey experiment 166, 178, 179  
 minerals 109, 145  
 molecular ions 74  
 moment of inertia 26, 31  
 monosaccharides 19  
*Moon* XXIV, 109, 180, 181  
 Mt. Lemmon Telescope 186  
 Mt. Wilson Observatory 6  
*Murchison meteorite* 30, 67, 117, 118, 120, 183  
*Murray meteorite* 30  
 myristic acid 19
- n**
- $\text{N}_2$  27  
 $\text{N}_2\text{O}$  112  
 $\text{NaCl}$  61  
 $\text{NaCN}$  61  
 nanodiamonds 13, 15, 67, 69, 137, 140  
 nanoparticles 115, 137  
 nanotubes 13, 15, 69, 133  
 naphthalene ( $\text{C}_{10}\text{H}_8$ ) 58  
 natural gas 153, 154  
 $\text{NCO}^-$  174  
 ND 72  
*Neptune* 44, 109, 113  
 neutron capture 3  
*NGC 1068* 92  
*NGC 1333* 83, 84  
*NGC 2068* 83, 84  
*NGC 300-OT* 173  
*NGC 3094* 92  
*NGC 5195* 130  
*NGC 5506* 92
- NGC 6240* 93  
*NGC 6334* 44  
*NGC 6572* 141  
*NGC 7023* 69, 128  
*NGC 7027* 7, 9, 42, 49, 73–75, 129, 138, 148  
*NGC 7172* 92  
*NGC 7479* 92  
 nickel monochloride ( $\text{NiCl}$ ) 62  
 nitriles 35, 72, 122, 166, 174  
 nitrogen heterocyclics 117  
 NO 28  
 Nobeyama 45-m Telescope 47, 72, 73, 80, 81  
 nova outburst 172  
 novae 171, 173  
 NRAO 11-m telescope 31, 33, 34, 38, 72  
 nuclear spin 28, 31, 35, 37, 43, 44, 51, 58, 62  
 nucleation 18, 169  
 nucleic acids 6, 63, 65, 165, 174, 175  
 nucleobases 1, 22, 65, 157  
 nucleoside 21, 22  
 nucleosynthesis 3, 5, 90, 188  
 nucleotides 21, 22, 35
- o**
- $\text{O}_2$  27, 28, 112  
 objective prism 75  
 $\text{OCN}^-$  115  
 Odin satellite 57, 71  
 $\text{OH}$  6, 41  
 $\text{OH}^+$  72  
 oil 13, 157, 185, 189  
 olivines 145  
 onosaccharides 65  
 Onsala Space Observatory 71, 73  
 Oort Cloud 123  
 Oparin–Haldane hypothesis 179  
 optical depth 77  
 organic refractory matter 122, 166  
*Orgueil meteorite* 117  
*Orientale Basin* 181  
*Orion BN* 82  
*Orion KL* 33, 37, 44, 63, 70, 71, 82  
*Orion Molecular Cloud* 82  
*Orion Nebula* 150  
 ortho 28, 31, 35, 43–45, 47, 53, 55  
 Owen Valley Radio Observatory (OVRO) 71  
 Owens Valley Millimeter Array 31
- p**
- P* branch 27  
 PAH clusters 147  
 palmitic acid 19  
 panspermia 179

- para 28, 31, 35, 43–45, 47, 53, 55  
partition function 77  
peat 18, 113  
*Peekskill meteorite* 181  
pentacene ( $C_{22}H_{14}$ ) 58  
pentamantanes 14  
peptide bond 19, 20, 40, 174  
petroleum 14, 154–157  
PH 57  
phenanthrene ( $C_{14}H_{10}$ ) 58  
phenols 29, 117  
Phobos 109  
*Phoebe* 115  
phonons 145  
phosphate 56  
phosphine ( $PH_3$ ) 56  
photochemistry 44, 107  
photodissociation 44, 79, 114, 165, 166  
photodissociation regions 79  
photoelectric effect 147  
photoionization 101, 165  
photoluminescence 87, 136, 146  
photosynthesis 19, 112, 182, 189  
phthalazine 162  
planetary atmospheres 28, 44  
planetary nebulae 7, 9, 75, 100, 136  
planetesimals 183  
*Pluto* 109, 113, 124  
PN 57  
PO 57  
polyacetylenes 114, 169  
polyacetylenic chains 29  
polyatomic molecules 28  
polycrystalline graphite 136  
polycyclic aromatic hydrocarbons (PAH) 58, 60, 133, 147, 152, 157, 169, 186  
polymerization 107  
polymers 6, 174  
polypeptides 19, 20, 174  
polysaccharides 19, 160  
polynyes 16  
polyyynyl radical chains 45  
POM 166  
post-AGB evolution 169  
post-AGB stars 41  
presolar grains 67, 183, 187  
*Pribram meteorite* 181  
primordial soup 179  
prolate asymmetric rotator 37, 63  
prolate symmetric rotator 30, 33, 38  
proline 65  
propadienylidene 54, 132  
propadienylidene ( $H_2CCC$ ) 45, 47  
propanal ( $CH_3CH_2CHO$ ) 32, 56  
propane ( $C_3H_8$ ) 12, 28, 153, 154  
propanone 117  
propenal ( $CH_2CHCHO$ ) 32, 64, 65  
propyl group 12  
propylene oxide 55, 56  
propynal ( $HC\equiv CCHO$ ) 32  
propyne 50  
propynl 52  
propynylidene 54  
proteins 6, 19, 63, 174, 175  
protoplanetary nebulae 7, 69, 75, 100, 104, 129, 137, 138, 141, 153, 154, 157, 168, 173  
pumping mechanism 32  
purine ( $c-C_5H_4N_4$ ) 6, 21, 22, 52, 65, 174  
pyrene ( $C_{16}H_{10}$ ) 58  
pyridine 35  
pyrimidine ( $c-C_4H_4N_2$ ) 6, 21, 22, 52, 65, 66, 174  
pyrolysis 150, 169  
pyrolysis gas chromatography 111, 117  
pyroxenes 145  
pyrrole ( $C_4H_5N$ ) 35, 65, 66
- q**  
quanine 65, 174  
quasars 3, 5, 90, 131  
quenched carbonaceous composites (QCC) 136, 137, 152  
quinazoline 162  
quinoline 35  
quinoxaline 162
- r**  
*R* branch 27  
*R Cor Bor* 68  
radiation transfer 5  
radiative recombination 165  
radicals 41, 44, 45, 62, 74  
Raman spectroscopy 162  
recombination lines 79  
red giants 3  
redshift 3, 90  
reflection nebulae 7, 83, 136, 187  
refractory molecules 61  
refractory oxides 144, 145  
ribose 64, 65  
RNA 21, 22, 65, 175  
rotational constant 26, 31, 40, 58, 63  
ruby 145
- s**  
s process 3  
saccharine 19

- sapphire 145  
 satellites 109  
*Saturn* 109, 113  
 scanning transmission x-ray microscopes (STXM) 111  
 scattering 145  
 selection rules 35, 43, 53  
 semi-anthracite 18  
 semiconductor 67, 146  
 serine 168  
 SEST 15-m telescope 34, 72  
*Sgr A\** 44  
*Sgr B2* 30, 32–34, 37, 39–41, 44, 49, 50, 63–65, 72, 78, 81  
 SiC 67, 99, 144, 183, 187  
 silicates 90, 183  
 small carbonaceous molecules 149  
 smoke 18, 160  
*SMP LMC* 58 92  
*SMP SMC* 16 69  
 SN 1987A 131  
 solid-state nuclear magnetic resonance (NMR) spectroscopy 111, 117  
 soot 15, 17, 18, 149, 150, 160, 169  
 spectral energy distribution 89, 90  
 spin-orbit interaction 41  
 spiral arms 79  
 Spitzer IRS 90–92, 94, 124, 128–130, 132, 138, 140, 141, 172, 173  
 starburst galaxies 89, 90  
 Stardust mission 122  
 statistical weights 37  
 stearic acid 19  
 stellar atmospheres 5, 150  
 stellar winds 3, 7, 97, 150, 183, 188  
 stereo isomers 65  
 stretching modes 9, 25, 28, 29, 37, 44, 67, 84, 120, 149, 166  
*Suavjarvi* 180  
 Subaru Telescope 124  
 sucrose 19  
 Sudbury 180  
 sugars 2, 6, 64, 116, 175, 178  
*Sun* 109, 112  
 sunspots 112  
 supernovae 3  
 surface migration 169  
 surface reactions 165  
 symmetric rotators 45  
 symmetric stretch 25  
 symmetric top rotator 26, 50
- t**  
*Tagish Lake* meteorite 117, 118, 181
- tar 179  
*Tc 1* 69  
 terrestrial planets 109, 182  
 tetracene ( $C_{18}H_{12}$ ) 58  
 tetramantane 14  
 thermodynamic equilibrium 5  
 thioformyl cation ( $HCS^+$ ) 71  
 tholins 116, 123, 126, 157, 159–162, 179, 186  
 thymine 21, 22, 65  
*Titan* 51, 109, 113–115, 159  
*TMC-1* 32, 45, 46, 48, 50, 52, 79, 80  
 torsion 29, 30  
 Trans-Neptunian Objects (TNO) 123, 159  
 transition metals 62  
 translucent clouds 84  
 triacetylene ( $C_6H_2$ ) 29, 107, 169  
 triamantane 14  
 triple- $\alpha$  reaction 97  
*Triton* 109, 113, 115  
 turbulence 7
- u**  
 ultraviolet photolysis 115, 159, 166, 168  
 unidentified infrared emission (UIE) 58, 128, 129, 141, 171, 187  
 unidentified lines 54, 75  
 United Kingdom Infrared Telescope (UKIRT) 92  
 uracil 21, 65, 157  
*Uranus* 109, 113  
 urea 2, 157
- v**  
*V2362 Cyg* 171, 172  
*V705 Cas* 172  
 valence bands 146  
*vdB 133* 83, 84  
*Venus* 109  
 vibrational modes 25, 28, 29, 31, 37, 44, 49, 54, 55, 58, 68, 105, 129, 145, 147–149, 160, 173, 190  
 vinyl alcohol ( $H_2C=CHOH$ ) 30, 56  
 vinyl cyanide ( $CH_2CHCN$ ) 63  
 vinylidene ( $H_2CC$ ) 45  
 vital force 178  
 vitalism 1  
 VLA 5  
 VLT 124  
 voalene ( $C_{32}H_{14}$ ) 58  
 Voyager 44, 114  
 Vredefort 180  
*VY CMa* 73

**w**

W 51 37, 63, 72  
water ( $H_2O$ ) 28, 74

**x**

X-ray absorption near-edge structure  
spectroscopy 111, 120  
X-ray diffraction 161  
xanthine 157

**y**

yeast 2  
yellow stuff 166

**z**

$\zeta$  *Oph* 44, 49  
 $\zeta$  *Per* 49