

CONTENTS

1. GENERAL PRINCIPLES OF HEAT ENGINE OPERATION 1—61

1.1.	Heat	1
1.2.	Expansion and Contraction of Solids	2
1.3.	Expansion and Contraction of Liquids	2
1.4.	Expansion and Contraction of Gases	3
1.5.	Speed and Acceleration	3
1.6.	Weight	3
1.7.	Acceleration Due to Gravity	3
1.8.	Mass—Inertia	3
1.9.	Force	4
1.10.	Work	4
1.11.	Energy	4
1.12.	Power – Horse Power	4
1.13.	Torque – Moment of a Force	5
1.14.	Work Done by Torque	5
1.15.	Power and Torque	5
1.16.	Machine	5
1.17.	Velocity	5
1.18.	Mechanical Advantage	5
1.19.	Friction	6
1.20.	Mechanical Efficiency of a Machine	6
1.21.	Objectives of Studying IC Engine Theory	6
1.22.	Basic and Derived Quantities	6
1.23.	Forms of Energy	8
1.24.	1st Law of Thermodynamics	9
1.25.	Process	9
1.26.	Analysis of Non-flow Processes	10
1.27.	First Law of Thermodynamics Analysis of IC Engines	11
1.28.	Useful Thermodynamics Relations	12
1.29.	Engine Performance Parameters	13
1.30.	Air Standard Cycles	15
1.31.	Important Practical Air Cycles For Automotive Applications	17
1.32.	Constant Volume or Otto Cycle	17
1.33.	Diesel Cycle	20
1.34.	Dual Combustion (Mixed or Limited Pressure) Cycle	22
1.35.	Comparison of Otto, Diesel and Dual Combustion (Limited-Pressure) Cycles	23
1.36.	Fuel-Air Cycles	25
1.37.	Significance of Fuel-Air Cycles	25
1.38.	Composition of Cylinder Gases	26
1.39.	Variation of Specific Heats	26
1.40.	Loss Due to Variation of Specific Heat	27
1.41.	Dissociation Chemical Equilibrium Loss	28

1.42.	Effect of Number of Moles	29
1.43.	Comparison of Air-Standard and Fuel-Air Cycles	29
1.44.	Effect of Operating Variables	30
1.45.	Actual Cycles	33
1.46.	Comparison of Thermodynamic and Actual Cycles	34
1.47.	Basic Requirements of Automotive Engines	38
1.48.	Automotive Engine	40
1.49.	Engine Nomenclature	41
1.50.	Standard Terminology	43
1.51.	Potential Horsepower	45
1.52.	Four Stroke Cycle for Spark-ignition Engines ..	46
1.53.	Actual Cycles of Engines	49
1.54.	Valve Timing of Four-Stroke Cycle	50
1.55.	Two-Stroke Cycle of Operations	52
1.56.	Indicator Diagram—Mean Effective Pressure ...	53
1.57.	Factors Governing M.E.P.	54
1.58.	Indicated Power Output (I.P.O.)—Indicated Horsepower (I.H.P.)	55
1.59.	Brake Mean Effective Pressure (B.M.E.P.) and Brake Power Output (B.P.O.)	56
1.60.	Mechanical Efficiency of Engine	58
1.61.	Characteristics Speed Power Curves (I.M.E.P., I.P.O., B.P.O. and B.M.E.P.)	58
1.62.	Torque Curve	58
1.63.	Specific Fuel Consumption	59
1.64.	Limiting Factors	60
1.65.	S.A.E. Gross and Net Horse Power Ratings	60
1.66.	R.A.C. Rating	60
1.67.	Din Rating	60
	■ Theory Questions	60

2. FUNDAMENTALS OF ELECTRICITY, MAGNETISM AND ELECTRONICS 62—89

2.1.	Introduction	62
2.2.	Static Electricity	64
2.3.	Matter—Molecule—Atom	64
2.4.	Electron Theory of Electricity	65
2.5.	Current	66
2.6.	Current Flow	66
2.7.	Voltage (Electromotive Force)	67
2.8.	Conductors	68
2.9.	Insulators	68
2.10.	Resistance	68
2.11.	Temperature Effect on Conductor Resistance	69

2.12.	Ohm's Law	69
2.13.	Types of Circuits	69
2.14.	Voltage Drop	71
2.15.	Electrical Work and Power	71
2.16.	Electronic Devices	71
2.17.	Direct and Alternating Current	75
2.18.	Effects of an Electric Current	76
2.19.	Short Circuit, Open Circuit, Fuse	76
2.20.	Earth Return and Twin-Wire Circuits	76
2.21.	Magnetism	76
2.22.	Magnetic Fields—Magnetic Lines of Force	76
2.23.	Unlike Poles Attract, Like Poles Repel	77
2.24.	Horseshoe Magnet	78
2.25.	Domains	78
2.26.	Permanent Magnets	78
2.27.	Theory of Permanent Magnets	78
2.28.	Electromagnetism	79
2.29.	Magnetic Conductivity-Permeability	81
2.30.	Electromagnetic Induction	81
2.31.	Solenoids	83
2.32.	Electrical Symbols	83
2.33.	Electronic Circuits	83
2.34.	Electronic Advances in Automotive Field	88
	■ Theory Questions	89

3. ENGINE TYPES AND ENGINE BALANCE 90—131

3.1.	Classification of Automotive Engines	90
3.2.	Engine Balance	105
3.3.	Single and Multi-cylinder Engines	108
3.4.	Firing Order	111
3.5.	Causes of Unbalance	111
3.6.	Balancing of Multi-Cylinder Engines	112
3.7.	Cylinder Arrangements, Balance and Firing Orders of Multi-Cylinder Engines	115
3.8.	Conventional Layout	125
3.9.	Power Overlap	125
3.10.	Flexible Support Mountings	126
	■ Theory Questions	131

4. CONSTRUCTIONAL DETAILS OF AUTOMOTIVE ENGINES—STRUCTURE AND MECHANISM 132—229

4.1.	Introduction	132
4.2.	Terminology	134
4.3.	Cylinder Block and Crankcase	137
4.4.	Materials For Cylinder Block and Crankcase ..	140
4.5.	Bell Housing	143
4.6.	Timing Case	144
4.7.	Cylinder Liners	145
4.8.	Engine Top End Construction	146
4.9.	Cylinder Head Materials	154
4.10.	Cylinder Head Gasket	154
4.11.	Oil Pan	155

4.12.	Pistons	156
4.13.	Piston Materials	160
4.14.	Expansion Problem in Pistons	162
4.15.	Piston Temperature	165
4.16.	Head Shape	166
4.17.	Piston Rings	166
4.18.	Ring Material	176
4.19.	Causes of Ring Failures	176
4.20.	Piston Pin (Gudgeon Pin)	177
4.21.	Piston Guided Connecting Rod	179
4.22.	Piston Pin Offset	179
4.23.	Crankshaft System and Bearings	179
4.24.	Flywheel	184
4.25.	Vibration Damper	185
4.26.	Main Bearings	186
4.27.	Thin Walled Bearings—With Two Half-liners ..	189
4.28.	Thrust Bearings	190
4.29.	Bearing Materials	191
4.30.	Main Caps	191
4.31.	Connecting Rods	192
4.32.	Timing Drive	196
4.33.	Valve Mechanisms	200
4.34.	Valve Train Components	201
4.35.	Valve Spring Assembly Construction	206
4.36.	Valve Rotation And Valve Rotators	208
4.37.	Valve Train Construction	209
4.38.	Camshaft Construction	210
4.39.	Valve Timing	210
4.40.	Stock and High Performance Camshafts	211
4.41.	Camshaft Design Considerations	212
4.42.	Cam Profile	214
4.43.	Valve Lifter Construction	215
4.44.	Hydraulic Lifter Construction	217
4.45.	Mechanical Lifter Construction	219
4.46.	Push Rod Construction	220
4.47.	Rocker Arm Construction	221
	■ Theory Questions	227

5. AUTOMOTIVE ENGINE LUBRICATION 230—285

5.1.	Introduction	230
5.2.	Essentials of a Lubricating System	230
5.3.	Functions of a Lubricating System	231
5.4.	Lubricating Oil (Engine Oil)	231
5.5.	Principles of Lubrication	231
5.6.	Types of Lubrication	233
5.7.	Functions of Lubricating Oil	235
5.8.	Properties of Lubricating Oil	236
5.9.	Oil Additives	242
5.10.	Lubricating Oils	243
5.11.	Blending and Compounding	243
5.12.	Lubricating Systems	244
5.13.	Units of Force Feed Lubrication System	248
5.14.	Lubricating Oil Circuit	262

5.15.	Oil Sealing Arrangements	271
5.16.	Crankcase Breathing	273
5.17.	Positive Crankcase Ventilation (PVC)	275
5.18.	Crankcase Ventilation Fittings	275
5.19.	Lubrication System Troubles and Remedies	276
5.20.	Engine Friction	278
5.21.	Oil Level Indicator	283
	■ Theory Questions	283

6. EXHAUST SYSTEM 286—298

6.1.	Introduction	286
6.2.	Units of Exhaust System	286
6.3.	Exhaust Manifold	288
6.4.	Thermostatic Heat Control Valve	289
6.5.	Silencers or Mufflers	290
6.6.	Types of Mufflers	291
6.7.	Piping, Support Mountings and Connections .	294
6.8.	Air Injection Pump and Fittings	295
6.9.	Air Injection Pump	296
6.10.	Backpressure	297
6.11.	Exhaust System Corrosion	297
6.12.	Catalytic Converters	298
6.13.	Drain Pipe	298
	■ Theory Questions	298

7. ENGINE COOLING SYSTEM 299—348

7.1.	Necessity of Engine Cooling	299
7.2.	Methods of Heat Transfer	300
7.3.	Antifreeze	301
7.4.	Engine Cooling Media	302
7.5.	Water Cooling System	304
7.6.	Forced Circulation System	306
7.7.	Air Cooling System	340
7.8.	Forced Circulation Air Cooling System Components	341
7.9.	Interrelationship of Cooling System and Other Engine Systems	342
	■ Theory Questions	346

8. FUELS AND FUEL SUPPLY SYSTEM OF SPARK IGNITION ENGINES 349—383

8.1.	Introduction	349
8.2.	Petroleum	350
8.3.	Making I.C. Engine Fuels	350
8.4.	Products of Refining Process	352
8.5.	Fuels For S.I. Engines	352
8.6.	Gasoline Fuel Properties	353
8.7.	Octane Rating	362
8.8.	Octane Number	363
8.9.	Octane Number Requirements	366
8.10.	Blending Agents	368
8.11.	Additives	368
8.12.	LPG as SI Engine Fuel	370

8.13.	Fuel Supply System	370
8.14.	Other Gasoline Additives	379
8.15.	Fuel For Automotive Engines	379
8.16.	Alternative Fuels	380
8.17.	Air Filters	382
8.18.	Fuel Pump Tests	382
	■ Theory Questions	383

9. PROCESS OF COMBUSTION IN SPARK IGNITION ENGINES 384—430

9.1.	Introduction	384
9.2.	SI Engine Combustion Process	386
9.3.	Range and Rate of Burning	387
9.4.	Stratification of Cylinder Charge	388
9.5.	Mixture Strength and Performance	388
9.6.	Turbulence	388
9.7.	Delay Period	389
9.8.	Rate of Flame Propagation	390
9.9.	Combustion Chemistry	390
9.10.	Homogeneous Mixture	390
9.11.	Heterogeneous Mixture	390
9.12.	Ignition Limits	391
9.13.	Combustion in SI Engines	391
9.14.	Combustion Stages in SI Engine	391
9.15.	Flame Front Propagation	393
9.16.	Concept of Combustion Quality	393
9.17.	Factors Affecting Ignition Lag	394
9.18.	Effect of Engine Variables on Flame Speed	395
9.19.	Rate of Pressure Rise	397
9.20.	Normal Combustion	397
9.21.	Abnormal Combustion	399
9.22.	Phenomenon of Detonation or Knocking in SI Engines	400
9.23.	Effect of Detonation	403
9.24.	Theories of Detonation	404
9.25.	Knock Limited Parameters	405
9.26.	Effect of Engine Variables on Knock or Detonation	405
9.27.	Factors Affecting Combustion	409
9.28.	Control of Detonation	415
9.29.	Detection of Detonation or Knocking	415
9.30.	Some Facts About Detonation	416
9.31.	Abnormal Combustion Knock-Surface Ignition	416
9.32.	Pre-ignition	418
9.33.	Pre-ignition Versus Detonation	420
9.34.	Knock Sensing System	421
9.35.	Post-ignition Effect—Dieseling	421
9.36.	Engine Rumble	422
9.37.	Spark Knock	422
9.38.	Dopes—Antiknock Substances	422
9.39.	Antiknock Value	422
9.40.	SI Engine Combustion Chamber Designs	422

9.41.	Basic Requirements of a Good Combustion Chamber	423
9.42.	Combustion Chamber Design Principles	423
9.43.	Historical Review of Combustion Chamber Design	424
9.44.	Types of Combustion Chamber	427
9.45.	Future Trends	430
	■ Theory Questions	430

10. CARBURATION AND FUEL INJECTION SYSTEMS IN SI ENGINES 432—506

10.1.	Introduction	432
10.2.	Engine Suction	433
10.3.	Volumetric Efficiency	434
10.4.	Throttling	434
10.5.	Factors Which Determine Air and Gasoline Flow	435
10.6.	Methods of Carburation	435
10.7.	Properties of Air-Gasoline Mixtures	436
10.8.	Mixture Strength Requirements	437
10.9.	Full Consumption Loop or Hook Curve	439
10.10.	Mixture Requirements For Steady State Operation	439
10.11.	Mixture Requirements for Transient Operating Condition	440
10.12.	Venturi Carburetor System	442
10.13.	Air Cleaner and Silencer	442
10.14.	Carburetor	444
10.15.	Complete Carburetor	448
10.16.	Fixed Choke Type of Carburetor	448
10.17.	Carburetor Systems	450
10.18.	Mixing Chamber With Multiple Venturies	459
10.19.	Compound Carburation System	460
10.20.	Constant Vacuum, Variable or Expanding-choke Carburetor	461
10.21.	Induction or Intake Manifold	463
10.22.	Design Requirements	468
10.23.	Indications of Mixture Strength	472
10.24.	Computerized Systems	472
10.25.	Computer Controlled Carburetors	473
10.26.	Gasoline Injection	477
10.27.	Fuel Injection System For SI Engines	479
10.28.	Classifying Gasoline Injection Systems	480
10.29.	Classifying The Control Systems	482
10.30.	Gasoline Injection Components	483
10.31.	EFI Injector Construction	484
10.32.	Injector Pulse Width	485
10.33.	Throttle Body (Multiport Injection)	485
10.34.	Controlling The Fuel Injectors	488
10.35.	Components of a Multipoint Fuel Injection System	490
10.36.	Multi-point Injection—Lucas Hot-wire	493
10.37.	Multipoint Port Injection Systems	498
10.38.	Multipoint Injection—Bosch 'L' Variations	501

10.39.	Single-Point Injection-Bosch Mono Jetronic ..	503
10.40.	Sequential Multipoint Injection	504
	■ Theory Questions	505

11. IGNITION SYSTEMS 507—566

11.1.	Introduction	507
11.2.	Function of an Ignition System	507
11.3.	Fundamental Laws	507
11.4.	Requirements of an Ignition System	509
11.5.	Types of Ignition Systems	509
11.6.	Generation of High Tension	509
11.7.	Fuel Consumption and Exhaust Emissions	510
11.8.	Conventional Ignition System Components ..	511
11.9.	Battery-Ignition System	511
11.10.	Ignition Timing	523
11.11.	Sparking Plugs	532
11.12.	Solid State Ignition Systems	539
11.13.	Inductive Discharge Systems	542
11.14.	Hall Effect Ignition Systems	545
11.15.	Electronic Ignition System Description	547
11.16.	Programmed Ignition System	555
11.17.	Distributorless Ignition	559
11.18.	Direct Ignition	561
11.19.	Combined Ignition and Fuel Management Systems	562
11.20.	On Board Diagnostics (OBD)	562
	■ Theory Questions	565

12. DIESEL (COMPRESSION IGNITION-CI) ENGINE 567—626

12.1.	Introduction	567
12.2.	Four-Stroke Diesel Engine Operation	567
12.3.	Combustion Process	569
12.4.	Diesel Engine Combustion Chamber	569
12.5.	Cetane Rating	570
12.6.	General Description	570
12.7.	Diesel Engine Construction	571
12.8.	Diesel Engine Lubrication System	577
12.9.	Diesel Engine Starting System	577
12.10.	Diesel Engine Cooling System	577
12.11.	Diesel Fuel Injection System	578
12.12.	Requirements of a Diesel Fuel Injection System	581
12.13.	Diesel Injection Pump	581
12.14.	Diesel Injection Pump Types	583
12.15.	Diesel Injection System Operation	590
12.16.	Fuel Injector	592
12.17.	Types of Injectors	594
12.18.	Heat Release Pattern and Fuel Injection	596
12.19.	Electronic Control of Diesel Injection	597
12.20.	Computer Controlled Diesel Injection	598
12.21.	Diesel Engine Sensors	598
12.22.	Computer Controlled Injection Pump	598
12.23.	Electronic Governor	599

12.24.	Diesel System Computer	599
12.25.	Fail Safe System	599
12.26.	Cold Starting	599
12.27.	CI Engine Fuels	600
12.28.	Comparison of SI and CI Engines	606
12.29.	Combustion in CI Engines	608
12.30.	Stages of Combustion in CI Engines	609
12.31.	Air-Fuel Ratio in CI Engines	610
12.32.	Delay Period or Ignition Lag	611
12.33.	CI Engine Combustion Chambers	615
12.34.	Methods of Generating Air-swirl in CI Engines	615
12.35.	Cold Starting of CI Engines	622
12.36.	Modern Starting Aids of High Speed Engines	623
12.37.	Diesel Knock	623
12.38.	Methods of Controlling Diesel Knock (Reducing Delay Period).....	624
	■ Theory Questions	625

13. ALTERNATE AUTOMOTIVE ENGINES 627—659

13.1.	Introduction	627
13.2.	Stratified-Charge SI Engines	627
13.3.	Advantages of Burning Leaner Overall Fuel-Air Mixtures	628
13.4.	Methods of Charge Stratification	629
13.5.	General Characteristics of Stratified Charge Engines	636
13.6.	Two-Stroke Engines	636
13.7.	Theoretical p-v Diagram For 2-stroke Gasoline Engine	637
13.8.	Actual p-v Diagram For 2-stroke Gasoline Engine	638
13.9.	Comparison of 2-stroke and 4-stroke Cycle IC Engines	638
13.10.	Port Timing For 2-stroke Engines	639
13.11.	Scavenging Process	639
13.12.	Types of 2-stroke Cycle Engines	640
13.13.	Definitions and Terminology	641
13.14.	Theoretical Scavenging Processes	643
13.15.	Actual Scavenging Process	644
13.16.	Scavenging Systems	644
13.17.	Comparison Of Scavenging Methods	646
13.18.	Scavenging Pumps	647
13.19.	Advantages of 2-stroke Cycle Engines	648
13.20.	Disadvantages of 2-stroke Cycle Engines	648
13.21.	Comparison of SI and CI Engines	648
13.22.	Wankel (Rotary Piston) Engine	650
13.23.	Rotary Engine Performance	650
13.24.	Principle of Operation	650
13.25.	Features of The Rotary Engine	653
13.26.	Construction Details	653
13.27.	Lubrication System	656

13.28.	Rotary Engine Cooling	656
13.29.	Fuel Supply System	657
13.30.	Gas Turbine	658
13.31.	Electric Motor-electric Car	659
13.32.	Hybrid Power Source	659

14. TURBOCHARGING AND SUPERCHARGING SYSTEMS ... 660—675

14.1.	Introduction	660
14.2.	Supercharging of SI Engines	661
14.3.	Thermodynamic Cycle with Supercharging	661
14.4.	Supercharging Power	662
14.5.	Supercharging of CI Engines	662
14.6.	Superchargers	662
14.7.	Passenger Car Supercharging	663
14.8.	Effect of Supercharging on Performance of The Engine	664
14.9.	Types of Superchargers	665
14.10.	Turbochargers	666
14.11.	Computer Controlled Turbocharging	670
14.12.	Limitations of Turbocharging	671
14.13.	Supercharged and Turbocharged Engine Modifications	671
14.14.	Turbocharger Life	673
14.15.	Turbocharger Problems	673
	■ Theory Questions	674

15. IC ENGINE TESTING AND PERFORMANCE 676—721

15.1.	Introduction	676
15.2.	Performance Parameters	676
15.3.	Basic Measurements	679
15.4.	Engine Performance Characteristics	695
15.5.	Performance of SI Engines	698
15.6.	Performance of CI Engines	701
15.7.	Factors Affecting Performance Characteristics of SI Engines	702
15.8.	Performance Maps	704

16. STORAGE BATTERY 722—752

16.1.	Introduction	722
16.2.	Electrolytic Conduction	722
16.3.	Batteries	723
16.4.	Battery Types	723
16.5.	Lead-Acid Battery	723
16.6.	Principles of Battery Operation	726
16.7.	Battery Construction	727
16.8.	Battery Capacity	732
16.9.	Battery Characteristics	733
16.10.	Battery Efficiency	734
16.11.	Visual Inspection	735
16.12.	Battery Leakage Test	735
16.13.	Battery Testing	735

16.14.	Battery Charging	740
16.15.	Jump Starting an Engine	743
16.16.	Dry Charged Batteries	744
16.17.	Battery Life and Maintenance	745
16.18.	Battery Troubles	747
16.19.	Choosing a Correct Battery	749
16.20.	Alkaline-Type Battery	749
	■ Theory Questions	751

17. STARTING SYSTEMS 753—789

17.1.	Starting Circuit	753
17.2.	Engine Starting	754
17.3.	Starting System Design	755
17.4.	Considerations Affecting Size of Starting Motor	755
17.5.	Starting System Circuit	758
17.6.	Starter Motor Principles	759
17.7.	Speed, Torque, Power and Efficiency	761
17.8.	DC Motor Characteristics	763
17.9.	Series Motor and Characteristics	764
17.10.	Starting Motor Internal Circuits	765
17.11.	Starter System Description	768
17.12.	Starting Motor Drive Mechanism	769
17.13.	Pinion Gear Drives	774
17.14.	Starting System Service	782
	■ Theory Questions	788

18. CHARGING SYSTEM 790—833

18.1.	Charging System Principles	790
18.2.	Generating System Principles	791
18.3.	Charging System Functions	792
18.4.	Automobile Electrical Loads	793
18.5.	Charging Voltages	793
18.6.	Charge Balance Calculation	794
18.7.	Charging System Parts	795
18.8.	Charging System Operation	796
18.9.	Alternating Current Generator	796
18.10.	Direct Current Generator	797

18.11.	Alternator Construction	798
18.12.	Alternator Operation	801
18.13.	Rectification of AC to DC	804
18.14.	Charging System Operation	808
18.15.	Charging System Circuits	809
18.16.	Charging System Regulation	810
18.17.	Voltage Regulators	811
18.18.	Current Regulation	815
18.19.	Solid-State Regulation	817
18.20.	Transistor Regulation	817
18.21.	Transistorized/Electronic Regulators	818
18.22.	Computerized Regulation	821
18.23.	Charging System Problems and Their Solutions	821
18.24.	Alternator Characteristics	823
18.25.	Charging System Service	824
	■ Theory Questions	832

19. ENGINE EMISSION CONTROL SYSTEMS 834—863

19.1.	Introduction	834
19.2.	Automotive SI Engine Emissions	834
19.3.	Exhaust Emissions	836
19.4.	SI Engine Emission Control	839
19.5.	Engine Design Modifications	839
19.6.	Emission Control Systems	841
19.7.	Exhaust Emission Controls	842
19.8.	Exhaust Emission Control Systems and Devices	843
19.9.	Computerized Emission Control Systems	857
19.10.	Diesel Engine Emissions	858
19.11.	Comparison of Diesel and Gasoline Engine Emissions	862
	■ Theory Questions	862

BIBLIOGRAPHY 864—865

PAPERS 866

INDEX 867—872