EXAMPLES.

1. Give reasons for the supposition that heat is not a substance.

2. Define the meaning of the terms 'work' and 'energy.'

3. Give an account of Davy's reasons for believing that heat is a form of energy.

4. Define a horse-power. What is the distinction between 33,000 foot-pounds and one horse-power?

5. A coal-mine 250 feet deep must, in order to keep the workings dry, have 108,000 gallons of water pumped out of it every hour. What horse-power must the engines exert merely to raise this water without taking any account of the friction of the machinery, &c.

6. State the distinction between potential' and 'kinetic' energy, and give an example of each.

7. Describe any experiment with which you are acquainted which proves that work may be done by the expenditure of heat.

8. State what is meant by 'temperature.' Describe how temperature is commonly measured. How many scales of temperature are there in common use in Europe? A thermometer registers 364° on the Fahrenheit scale: what would be the corresponding numbers on the Centigrade and Réaumur scales?

9. What is meant by the term 'specific heat'?

10. Describe an experiment which proves that the same quantity of heat imparted to equal weights of different substances affects the temperatures of the substances unequally.

11. A pound of cast-iron (specific heat = ·130) is made red-hot and plunged into two gallons of water of the temperature 60°. In quenching the iron the temperature of the water rises 9°: what was the original temperature of the hot iron?

12. What is meant by the mechanical equivalent of heat? What is the equivalent in foot-pounds of the British thermal unit? Work at the rate of a horse-power is expended for an hour in creating friction, the heat generated by which is all communicated to 10 cubic feet of water

contained in a non-conducting tank. The original temperature of the water was 60° : what will be its temperature at the end of the hour?

13. State Boyle's law connecting the pressure and volume of gas. Show how the law may be represented graphically. Prove that the curve which represents the varying pressures of a portion of gas when the volume is changed and the temperature is kept constant is a rectangular hyperbola.

14. A cylinder containing air is fitted with a gas-tight piston by means of which the contained air is compressed to one-fourth of its original volume. Will the final pressure be four times the original pressure immediately after the compression takes place? Give your reasons for your conclusion.

15. State what is meant by an isothermal line of a gas.

16. What is the general effect of raising the temperature of a portion of gas, first, when the volume is kept unchanged, and second, when the pressure is kept constant? State Charles' law, and give the formula which expresses it. A cylinder of 18 inches diameter and of indefinite length contains a cubic foot of air enclosed by a gas-tight piston. The cylinder is plunged into water which is kept at the temperature of 175° : to what height above the bottom of the cylinder will the piston be moved after the inclosed air has attained the temperature of the water?

17. State the distinction between Charles' and Dalton's laws.

18. Describe the air-thermometer, and state what is meant by the term 'absolute temperature.' Show how to deduce the number of degrees which the absolute zero is below the zero of the Fahrenheit scale on the assumption that Charles' law is true.

19. Show how to deduce from Boyle's and Charles' laws a formula connecting the volume, the pressure, and the absolute temperature of a portion of gas.

A pound of air of the temperature 32° and atmospheric pressure is heated up to 100° : what is the product of its pressure and volume at the latter temperature?

20. Establish the ratio between the specific heat of air heated, first, at constant volume, and, second, at constant pressure.

21. What is meant by the term 'latent' as distinguished from 'sensible' heat? When water is turned into steam, state the various ways in which heat is expended.

22. Is Boyle's law applicable to the case of expanding steam? State your reasons for your answer. Make a sketch of the isothermal line of steam of, say, 212°, and explain what the different portions of the line represent.

23. A portion of gas is enclosed in a cylinder under pressure, and is expanded so as to do work. How can you secure that the curve of expansion shall be a rectangular hyperbola?

24. Describe what is meant by a 'cycle of operations.'

25. Give a numerical expression for the quantity of heat required to raise the temperature of air from temperature t_1 to t_2: first, the volume of the air being kept constant; and, second, the pressure being kept constant.

26. A portion of gas is expanded isothermally from volume v_1 to v_2, the initial and final pressures being p_1 and p_2, and the temperature t. State how much heat is expended in doing external work; how much in doing internal work; and how much heat must be supplied to the gas in order that the condition of isothermal expansion may be fulfilled.

27. A portion of gas is expanded from volume v^1 to v^2, the equation of the curve of expansion being $p\,v^n =$ constant. Deduce an expression for the total quantity of heat expended during the operation.

28. When gas expands adiabatically, prove that the equation of the curve of expansion is $p\,v^\gamma =$ constant.

29. What will be the final temperature τ_2 of gas expanded adiabatically, the original temperature being τ_1 and the ratio of expansion r? What will be the total loss of heat by the gas during the expansion?

30. As a numerical application of the above, find the final temperature of air expanded adiabatically to double its volume, the initial temperature being 539° Fahrenheit. Find also the final temperature when the ratios of expansion are 3, 4, and 5. (A table of logarithms will be required for the solution.) The student should notice the great fall in temperature of gas expanding adiabatically as compared with steam, and draw his own conclusions as to the suitability of air as a medium for the working of heat-engines.

31. A cubic foot of air of the pressure 100 pounds per square inch and temperature 539° Fahrenheit is expanded adiabatically till its volume is doubled: construct a table showing the pressures and corresponding temperatures for the volumes 1·1, 1·2, 1·3, 1·4, &c. up to 2.

32. What are the essential conditions of working to realise a theoretically perfect heat-engine? Prove that if the essential conditions are realised the efficiency of the engine is represented by the fraction $\frac{\tau_1 - \tau_2}{\tau_1}$ where τ_1 and τ_2 are the absolute temperatures of the sources of heat and cold respectively.

33. A pound of coal will generate during combustion 14,000 units of heat. Supposing that a theoretically perfect heat-engine consumed one pound of coal per minute and that its limits of working temperature

were $\tau_1 = 2{,}440°$ and $\tau_2 = 60°$, what would be the horse-power developed by the engine?

34. What is the meaning of the terms 'specific volume' and 'relative volume' of steam? How may the relative volume be calculated when the specific volume is given? State Zeuner's law connecting the pressure and volume of dry steam.

35. State an approximate formula for the total heat of steam formed from water of the temperature t, the temperature of the steam when formed being T. Of the above a certain quantity is expended in doing external work: give Zeuner's approximate formula for the heat which thus disappears.

36. If p be the pressure of steam, and p_b be the back pressure in pounds per square inch; also, if H be the total heat of formation of a pound of steam, and v its specific volume: deduce expressions for the heat expended, the external work done, and the heat rejected per cubic foot of the contents of the cylinder in a non-expansive steam-engine.

37. A condensing non-expansive engine uses steam of the pressure of 60 pounds absolute; the back pressure is 2 pounds per square inch. How many pounds of water must be evaporated for this engine per effective indicated horse-power per hour?

N.B. The specific volume of steam of 60 pounds pressure is 7·037 cubic feet.

Ans. 33·7.

38. Supposing the feed-water in the above engine is taken from the condenser and has the temperature of 100°, what is the ratio of heat expended to work done?

N.B. The total heat of formation of steam of 60 pounds pressure is 1171·3 thermal units.

39. In an engine using steam expansively the pressure during admission is P_1 pounds per square inch, the volume when steam is cut off is V_1, the rate of expansion is r, and the back pressure, which is supposed to be uniform, is P_b. Find an expression for the effective work done, and also for the mean pressure, on the assumption that the expansion takes place in accordance with Boyle's law, and that there is no clearance.

40. In an engine using steam expansively the pressure during admission is $P_1 = 95$ pounds per square inch absolute. The back pressure $P_b = 3$ pounds per square inch. The volume of one pound of steam of pressure p_1 is v_1 cubic feet. The rate of expansion $r = 2$.

Find out the effective work per pound of steam in thermal units; and the total weight of steam supplied to the cylinder per effective indicated horse-power per hour.

The expansion is supposed to be hyperbolic, and clearance neglected and the steam dry at the end of the stroke.

Solution.—Let p be the final and p_m the mean pressure in pounds per square inch. Also, let v_2 = the specific volume of steam of pressure p_2. Then the total work done

$$= 144\, p_2 v_2 (1 + \log_e r)$$

The effective work done equals the foregoing minus the work done in overcoming the back pressure

$$= 144\, p_2 v_2 (1 + \log_e r) - 144\, p_b v_2 = 144\, p_2 v_2 \left(1 + \log_e r - \frac{p_b}{p_2}\right)$$

Now, multiplying v_2, i.e. the specific volume of dry steam of 42·5 pounds per square inch by $144 p_2$, and reducing to thermal units, we obtain the number 77·7. Hence the effective work done

$$= 77{\cdot}7\left(1{\cdot}696 - \frac{3}{42{\cdot}5}\right) = 126{\cdot}3 \text{ thermal units per pound of steam.}$$

Now one horse-power per hour $= \dfrac{33000 \times 60}{772} = 2565$ thermal units per hour $\therefore \dfrac{256}{126{\cdot}3} = 20{\cdot}3$ pounds

equals the weight of steam which must be supplied to the cylinder.

41. Find out what quantity of heat must be added to the steam during expansion in the above example, in order that the condition may be realised that it should be dry, and saturated at the end of the stroke.

Solution.—The symbol P is used throughout to denote the pressure per square foot corresponding with the pressure p per square inch. If steam of pressure p_2 be dry at the end of the stroke, it must have had imparted to it not only the heat of formation H_2 of dry steam of this pressure, but also the equivalent of heat corresponding to the work done over and above whatever work done is included in H_2. Now the work done included in H_2 equals the pressure 144 P_2 multiplied by the corresponding volume v_2 (see page 99). But the total work done equals the mean pressure P_m multiplied by the final volume v_2. Therefore the difference, or $P_m v_2 - P_2 v_2 = (P_m - P_2)v_2$, must be added to H_2. Hence the total heat in the steam at the end of the expansion, provided it be then dry and saturated,

$$= H_2 + (P_m - P_2)v_2.$$

Now the steam when admitted into the cylinder was at the pressure P_1, and its total heat of formation is H_1.

$$\therefore\ H_2 + (P_m - P_2)v_2 - H_1$$

must be added to the steam during expansion.

Substituting for P_m its value, the above expression becomes

$$P_2 v_2 \log_e r + H_2 - H_1$$

The value of $H_2 - H_1$ can be obtained from Table I.; or, if no table be at hand, its approximate value is ·305 thermal units for every degree of difference of temperature between steam of the pressures p_1 and p_2.

Applying these results to the case in hand, we have

$$P_2 v_2 \log_e r + H_2 - H_1 = 77 \cdot 7 \times \cdot 696 - \cdot 305(324° - 271°)$$
$$= 37 \cdot 9 \text{ thermal units per pound of steam used.}$$

But, as we proved in the previous example, 20·3 pounds of steam are used per effective horse-power per hour ;

$\therefore$ $20 \cdot 3 \times 37 \cdot 9 = 769 \cdot 37$ thermal units per horse-power per hour

must be supplied to the cylinder from a steam-jacket in order to keep the steam dry at the end of the stroke. This would be supplied by the liquefaction in the jacket of about ·7 pound of steam per hour. Hence the theoretical consumption of water in this engine working under the above conditions would be 21 pounds per hour, as against 33·7 in the case of Example 37.

42. What would be the theoretical quantity of water required in the above example if the steam-engine were a perfect engine working between the limits of temperature corresponding to the initial and the back pressures of the steam ?

43. State in what respects the action of a steam-engine differs from that of a perfect heat-engine.

44. State Navier's formula for the expansion of steam, giving the numerical constants.

45. Investigate an expression for the work done during expansion, using Navier's formula (instead of, as heretofore, assuming hyperbolic expansion), and taking account of the effect of clearance.

46. State De Pambour's theory of the steam-engine, and reduce it to mathematical form.

47. Analyse the nature of the resistances to the motion of stationary and locomotive engines.

(For numerical examples of the application of De Pambour's theory see pages 136 and 139).

48. Steam of 75 lbs. pressure above the atmosphere is used in a cylinder. It expands down to 4 lbs. absolute at the point of release. What is the ratio of expansion, supposing the clearance to occupy a space equivalent to 5 per cent. of the stroke, and the release to take place at a point 7 per cent. of the stroke, before the end ?

49. The stroke of a piston is 3 feet 6 inches, the ratio of expansion is 3·5 : at what pressure must the steam be admitted in order that at the release, which is supposed to take place at the end of the stroke, the steam may have expanded down to 5 lbs. absolute, the clearance being equal to 6 per cent. of the stroke?

50. A crane is employed to lift a maximum weight of one ton. The chain is wound round a barrel 2 feet in diameter, to which is made fast a spur wheel 4 feet in diameter, driven by a 9 inch pinion. The pinion is keyed to the crank axle of a two-cylindered engine, the diameter of each cylinder being 6 inches, and the stroke 1 foot. What mean pressure of steam will be required in order to lift the weight, without taking any account of the other resistances to the motion of the piston ?

51. A locomotive weighing 32 tons is drawing a train of 150 tons up an incline of 1 in 180, at a speed of fifteen miles an hour. The diameter of each cylinder is 18 inches, the stroke 24 inches, and the diameter of the driving-wheel 6 feet. What is the mean pressure of the steam required in order to overcome the resistance of the engine and train, without taking account of the other resistances to the motion of the piston ?

52. How is mass measured, and what units of mass are adopted in practice ?

For examples on the application of the laws of motion see pages 148 to 153.

For examples on fly-wheels see page 155.

53. Calling the weight of a body w, v the velocity with which it moves in a circle of radius r, prove that the centrifugal force $F = \frac{w v^2}{g r}$.

Also, deduce an expression for the centrifugal force when you are given the number of revolutions per minute (N), instead of the circular velocity.

54. Explain what is meant by the twisting moment on a crank shaft, and show how the variation in the twisting moments during a revolution may be represented graphically by a curve on a straight base.

55. Show by the principle of work that there is no loss of power in converting rectilinear into circular motion by means of a crank and connecting-rod.

The mean pressure in the cylinder is P lbs. per square inch : what is the mean tangential pressure on the pin of a crank of radius $= r$?

56. Supposing the motion of the crank-pin in its circle to be practically uniform, what influence has the fact that the connecting-rod is

finite in length, on the velocity of the piston in each of the four quarters of a revolution?

57. Show how to obtain the twisting moment on the crank graphically when the pressure on the piston is known, and the ratio of length of connecting-rod to length of crank is given, for any position of the crank-arm.

58. Explain the general effect of the inertia of the reciprocating parts in modifying the twisting moments on the crank. Explain the nature of a graphic diagram for exhibiting the pressures absorbed and restored by the reciprocating parts at different parts of the stroke, stating how you would calculate the initial and final pressures, taking no account of the length of the connecting-rod. Also explain how this graphic diagram would be altered, first, in the case of vertical engines by the effect of gravity on the reciprocating masses; and second, in the case of horizontal engines, when the ratio of the length of the connecting-rod to that of the crank is given.

59. Explain in detail the various steps to be taken in order to construct an exact curve of twisting moments, when you are provided with a pair of indicator diagrams, and the necessary data concerning weights and dimensions.

60. Explain the methods by which in practice uniformity of twisting moment is approximated to.

61. What are the essential data necessary in order to determine the weight of the fly wheel of an engine?

62. Explain the objects of cushioning the exhaust steam.

63. What area of passage would you give to a steam port for a cylinder of 24 inches diameter, 36 inches stroke, the engine making 45 revolutions per minute?

64. What are the advantages of making the working barrel of a cylinder of a separate detachable piece, called a liner?

65. Under what circumstances would you fit a steam-jacket to a cylinder, and what precautions would you adopt in designing the jacket?

66. Make a sketch of the general arrangements of the cylinder of a locomotive engine, showing a section through the cylinder and valve box.

67. Give a description, with sketch, of the piston-packings of a marine engine.

68. A locomotive piston of 18 inches diameter is provided with three half-inch packing-rings, so adjusted as to exert a pressure on the piston sides of 3 lbs. per square inch. The stroke is 24 inches, and the diameter of the driving-wheels 6 ft. 6 in. What horse-power is exerted in overcoming the friction of the pistons when the engine is running at the speed of 48 miles an hour, the co-efficient of friction between the rings and sides of the cylinder being taken as ·085?

69. Prove that so long as an engine runs in one direction pressure is only exerted upon one of the slide bars.

70. In designing motion blocks and slide bars, what should be the maximum pressure per square inch of bar surface allowed for?

71. Given the steam pressure, the diameter of cylinder, and the ratio of length of crank to connecting-rod, what is the maximum pressure on the slide bar?

72. What are the principal disadvantages of making the connecting-rod short relatively to the crank arm?

73. The diameter of a cylinder is 30 inches, the steam pressure 40 lbs. per square inch. What is the maximum strain in the connecting-rod when the latter is 4 times the length of the crank?

74. Make sketches of the big ends of connecting-rods (1) when the brass steps are held in place by a strap, and (2) when the end is solid. What effect on the length of the rod is produced driving in the cotter in each of these cases?

75. You are required to drive a slide valve having a travel of four inches from a main shaft of the diameter of seven inches: make a sketch of the method you would adopt, giving dimensions.

76. Investigate the moment of resistance of a hollow shaft, the exterior diameter of which is R and the interior r, and prove that with a given weight of metal you can turn out a stronger shaft by making it hollow rather than solid.

77. The indicated horse-power of an engine is 500, the number of revolutions 50 per minute. What should be the diameter of the crank shaft, the metal being steel having a shearing strength of 80,000 lbs. per square inch, and the factor of safety being 6?

78. Explain the action of Watt's governor and prove that the speed of revolution of the engine is inversely proportional to the square root of the height of the cone of revolution. What is the object of crossing the arms of a governor?

79. Explain the nature of the objections to extreme sensitiveness in a governor.

80. Make a sketch showing how the rate of expansion of an engine may be controlled by the governor.

81. A fly-wheel has a mean radius of 10 feet, and weighs 10 tons, the whole of which is supposed to be concentrated at the mean radius. The section of the rim is 160 square inches. What is the maximum safe speed the wheel can be run at, on the assumption that the tensile

strength of cast-iron is 15,000 lbs. per square inch, and that the factor of safety is 5? Also at what speed would the wheel burst asunder?

82. Sketch a D slide valve, and explain the action of outside and inside lap on the valve.

83. What is the meaning of the term 'lead'? Given a slide valve with a travel of $2\frac{1}{2}$ inches, outside lap of $\frac{1}{2}$ inch and lead of $\frac{1}{8}$ inch, what will be the throw and the angle of advance of the eccentric?

84. Make a sketch of an arrangement for reversing an engine fitted with a slide valve.

85. Make a sketch of Meyer's valve gear, and state under what circumstances it is desirable to fit a separate expansion valve to an ordinary slide valve. State clearly all the functions of the main and the expansion valves.

86. What are the disadvantages of slide valves? and make a sketch showing how these disadvantages are obviated in the Corliss engine. What is the object of the separate exhaust valves in the latter engine?

87. Make a sketch of the piston valve of a marine engine, and state what its advantages are.

88. Explain how the slide valves of marine engines are usually relieved of a portion of the pressure on their backs.

89. The back of the slide valve of a locomotive exposes 180 square inches of area. The pressure in the valve box is 140 pounds per square inch, which is partly balanced by the pressures acting on the under surfaces of the valve so that the average net force pressing the valve down is 130 pounds. The coefficient of friction has been experimentally proved to be ·22. The travel of the valve is 4 inches. All the other data of the engine are the same as in Example 68. What is the horse-power absorbed when the engine is running at 48 miles an hour in overcoming the friction of the valves?

90. Make a sketch of Joy's valve gear, and explain some of the advantages which it possesses over the ordinary eccentric gear.

91. Explain the principle of Zeuner's valve diagrams, and show, choosing any dimensions of valves &c. you like, how the diagram may be made to indicate the positions of the piston at which the steam admission, the cut-off, the release, the compression, take place.

92. Prove that with an eccentric valve motion the point at which compression commences must vary with the rate of expansion.

93. The travel of a slide valve is 8 inches, the outside lap 2 inches, the inside lap $\frac{1}{4}$ inch, the angle of advance 40°. Construct a Zeuner's diagram showing the positions of the crank when the admission takes place, the steam is cut off and released, the exhaust closed, and also the amount of the lead.

94. The travel of a slide valve is 4 inches, the angle of advance is 40°, the ratio of expansion is 1·25, the steam is released when the piston has still 3 per cent of the stroke to travel. Find the outside and inside lap, the lead, and the position of the crank when the steam is admitted and the exhaust closed. The ratio of length of connecting-rod to crank is to be neglected.

95. In an engine with a 3-feet stroke the length of the connecting-rod is 6 feet, the steam is cut off when the crank is at angles of 60° from the line of dead centres: what is the ratio of expansion in the forward and in the back stroke?

Numerous other problems in simple valve setting and designing will be found on pages 281 to 290.

96. In a Stephenson's link motion with open arms, you are required to fix the positions of the notches in the reversing lever quadrant by a geometrical construction, so that steam may be cut off when the crank makes angles of 45°, 60°, 90°, 120° and 135°, with the dead centres, choosing any dimensions you think proper for the various parts of the valves and gear.

97. What is the general effect on the lead and the point of compression of increasing the rate of expansion in Stephenson's link motion, (1) when the arms are open, (2) when the arms are crossed? Illustrate your answer by means of Zeuner's diagrams, the angles of advance of the virtual eccentrics corresponding with the various rates of expansion being found by geometrical method. Choose any convenient dimensions for the gear.

98. Show that when Zeuner's diagram is applied to the elucidation of Meyer's valve gear, a resultant circle can always be found the chords of which represent the distances apart of the centres of the two valves.

99. Is Meyer's valve gear suitable for use with engines which have to be reversed frequently? Illustrate your reply by means of a Zeuner's diagram, and state the best position for the eccentric of the expansion valve so as to secure the most uniform steam distribution for running in both directions.

100. Describe Richards' indicator with the help of illustrative sketches.

101. What points connected with the working of steam engines are revealed by indicator diagrams?

102. Being given the diagram of an expansive engine, state how you would estimate the mean pressure. What data in addition to the diagram would you require before you could calculate the power exerted by the engine?

103. Make a sketch of the theoretical diagram of a condensing engine, and show what modifications in the outline of the latter are to be expected in practice.

104. What effect has clearance on the shape of the diagram?

105. What are the leading characteristics of the diagrams of locomotive engines working at high rates of expansion?

106. Do the pressures recorded by indicator diagrams give the actual forces urging the piston? Give your reasons for your reply.

107. Why is it that when every care is taken in the valve-setting, the diagrams from the two ends of a cylinder often differ considerably in area and shape? Under what circumstances may this peculiarity be turned to account?

108. Explain exactly how you would draw the combined diagram of the two cylinders of a compound engine when you are provided with a diagram from each cylinder.

109. What are the principal causes which affect the back-pressure line of the diagram?

110. What is the meaning of the terms 'gross' and 'net' indicated power?

111. Are high rates of expansion economical in non-condensing engines? Give your reasons for your reply.

112. State how to ascertain if the valves and piston of an engine are steam-tight.

113. Explain how to measure the expenditure of steam accounted for by the diagram.

114. How many units of heat are obtained by the combustion of one pound of carbon with sufficient air to form, (1) carbonic oxide, (2) carbonic anhydride?

115. What is the minimum weight of air necessary to effect the complete combustion of one pound of carbon, and what should be the temperature of the products of combustion?

116. When a chemical combination of carbon and hydrogen is burnt in oxygen how would you estimate the heat of combustion?

117. What are the principal constituents of fuel?

118. A firegrate is 4 feet 6 inches long, and 3 feet wide; twenty pounds of coal are burnt on it per square foot of area per hour, with a supply of 24 lbs. of air per lb. of fuel. What is the temperature, and what the volume in an hour of the products of combustion, (1) as formed in the furnace; and (2) in the chimney, supposing the latter to be maintained at the temperature most suitable for draught-creation?

119. State the principal causes of the waste of fuel in boilers.

120. Describe a modern Lancashire boiler, and give illustrative sketches.

121. What are the principal ends gained by the use of Galloway tubes?

122. What precautions would you observe in placing the gusset stays in the flat ends of Lancashire boilers?

123. What are the principal peculiarities of locomotive boilers?

124. The firegrate area of a locomotive is 20·5 square feet. It is intended to burn on the average 50 lbs. of fuel per square foot of grate-surface per hour. How much heating-surface would you provide?

125. A modern marine high-pressure boiler has to supply steam to an engine indicating 560 horse-power, and which consumes 18 pounds of water per I.H.P. per hour. How much grate-area would you think it necessary to provide, and how much heating-surface, ordinary draught being used?

126. Give sketches showing the general arrangements and the approximate dimensions of the boiler which you would provide for the above purpose, the pressure being 90 lbs. absolute.

127. If the shell-plates were made of steel, what thickness would you employ, having reference to the Board of Trade rules?

128. What area of opening of safety-valves would you allow?

129. Why are the ends of tubes furthest from the furnace or combustion chamber of comparatively little use in absorbing heat when a boiler is new? and why are they likely to be more useful after the boiler has been worked for a time?

130. An engine is required to give out very varying quantities of power during the course of every hour. Would you provide for it a boiler of comparatively large or of comparatively small cubic contents? State your reasons.

131. Investigate the strength of a hollow cylinder with flat ends pressed from within, and prove that the strain in the plane of the axis is double that in a plane at right angles to it. Does the shape of the ends affect the strain transmitted by them to the boiler body?

132. How are internal furnaces and flues constructed so as to allow for expansion and contraction, and to provide against collapse?

133. On what does the strength of a hollow cylinder to resist collapse principally depend? Why are hollow cylinders pressed from without more liable to destruction than the same cylinders pressed with equal force from within?

134. State what you consider to be the principal advantages of Fox's corrugated flues.

135. Explain the action of, and illustrate by sketches the Bourdon pressure gauge.

136. Describe any of the structural arrangements with which you are acquainted for attaching the ends to the body of a boiler, and for strengthening them; also for attaching the furnace tube to the ends. State fully what precautions must be adopted in strengthening the flat ends.

137. A cylindrical land boiler is 7 feet 6 inches in diameter, and has to sustain a pressure of steam of 90 lbs. by the gauge. What thickness of mild steel shell-plates would you adopt for the shell?

138. The effect of punching rivet-holes is to compress a thin layer of the metal all round the hole, and to greatly increase its tensile strength, and, at the same time, to diminish its stretching power. When the holes are drilled the metal remains in its normal condition. What conclusions would you draw from these facts as to the relative strength of punched and riveted joints, and state your reasons?

139. Make sketches, including sections, of single and double riveted lap-joints.

140. State the methods in which a single riveted lap-joint may give way when subjected to tensile strain.

Ans. 1. The plate may tear asunder where its area is reduced, between the rivet-holes. 2. The rivets may shear asunder. 3. The metal between the rivet-holes and the edge of the plate may be crushed. 4. The plate may break across in front of the rivet-holes and at right angles to the edge. (N.B. The two latter causes of fracture may be provided against by giving the plates a sufficient depth of lap. As a rule, the portion of the plates which overlap should be not less than three times the diameter of the rivet-hole.)

141. Show how to proportion a single-riveted lap-joint so that the resistance of the plates to tearing may just equal the resistance of the rivets to shearing.

Ans. Let d = diameter of rivet in inches, t = thickness of plates, $\frac{\pi d^2}{4}$ = area of a rivet, p = pitch of rivets, i.e. distance apart from centre to centre, S = shearing strength of rivets per square inch, T = tensile strength of plates per square inch. Then area of section of plate between any two holes, multiplied by tensile strength of plate, must equal area of one rivet multiplied by the shearing strength of the material.

$$\therefore (p-d)t\text{T} = \frac{\pi d^2}{4}\text{S}.$$

As a general rule, the tensile and shearing strengths are equal for iron plates and iron rivets.

$$\therefore (p-d)t = \frac{\pi d^2}{4} \qquad \therefore p = \frac{\pi d^2}{4t} + d = \cdot 785\frac{d^2}{t} + d.$$

Which formula gives the pitch in terms of the thickness of plates and the diameter of the rivets.

142. In a single-riveted joint the plates are $\frac{3}{4}$ inch thick, the rivets are $1\frac{1}{8}$ inch diameter. What should be the pitch on the suppositions (1) that the shearing and tensile strengths are equal, and (2) that the safe tensile strength is 25 per cent. greater than the safe shearing strength?

143. What must be the diameter of the rivet in a single-riveted lap-joint so that the resistance of the rivet to crushing and shearing may be equal?

Ans. The resistance of the rivet to crushing equals its diameter multiplied by the thickness of the plate, multiplied by the resistance of the metal to crushing per square inch. The resistance of iron rivets in iron plates to crushing is double the resistance to shearing. The resistance of the rivet to shearing equals its area multiplied by the shearing strength of the metal per square inch.

$$\therefore t\,d\,2\text{S} = \frac{\pi d^2}{4}\text{S} \qquad \therefore d = \frac{8t}{\pi} = 2\cdot 55\,t.$$

The diameter thus obtained is, however, far larger than is admissible in practice.

N.B. A practical rule for the diameter of the rivet in terms of the thickness of the plate is

$$d = 1\cdot 2\,\sqrt{t}.$$

If the diameters of rivets progress by 16ths of an inch, then for single-riveted joints we may take the number of 16ths next above the diameter, as given by the formula, and for double-riveted joints the number of 16ths next below.

144. In a double-riveted lap-joint, find the pitch of the rivets so that the shearing and tensile strength of the joints may be equal, for iron plates and rivets.

Ans. Referring to *Ex.* 141, when the joint is double-riveted, we have the area of two rivets to shear instead of one.

$$\therefore (p-d)\,t = \frac{\pi d^2}{2} \qquad \therefore p = 1\cdot 57\frac{d^2}{t} + d.$$

N.B. By making use of this equation $d = 1\cdot 2\sqrt{t}$, and substituting this value of t in the above equation, we can obtain an expression for the pitch in terms of the thickness of the plate alone. When the pitch and diameter of the rivets are known the strength of the plate between the rivet-holes can be ascertained, and the strength of the joint compared with that of the whole plate can be calculated.

145. Make sketches, including sections of single-and double-riveted butt-joints, in both single and double shear.

146. Is there any difference between the strength of a single-riveted lap-joint and the corresponding butt-joint in single shear?

147. Show how to proportion a double-riveted butt-joint in double shear, so that the tensile strength of the plate between the rivet-holes may be equal to the shearing strength of the rivets (iron plates and rivets).

Ans. In this case (referring to *Ex.* 1) we have four rivet areas to shear instead of one.

$$\therefore (p-d)\,t=\pi\,d^2 \text{ and } p=\frac{\pi d^2}{t}+d.$$

N.B. In practice it is not found safe to calculate on the area of four rivets, and by the Board of Trade rules only $3\frac{1}{2}$ are allowed. Hence, taking this into consideration, and making use of the formula $d=1\cdot2\sqrt{t}$, we get

$$p=3\cdot95+d.$$

For plates of less than $\frac{3}{4}$ inch thickness, the results got by the above formula are greater than those adopted in practice, because the diameter of the rivets is generally less than what would be indicated by theory.

148. Enumerate the fittings required for a Lancashire boiler.

149. Describe the principle on which the injector works, and make a sectional sketch of an injector, showing how the steam and water supply can be adjusted.

Wha are the objections to creating a draught in the ordinary way by means of a funnel or chimney?

150. Make a sketch illustrating the ordinary weighted lever safety-valve. The diameter of opening of a safety-valve is 4 inches; the distance from the fulcrum to the centre of the valve is 5 inches; the lever is 21 inches long, weighs $3\frac{1}{2}$ lbs., and its centre of gravity is 8 inches from the fulcrum; the valve weighs 5 lbs. What weight must be hung one inch from the end of the lever so that steam may blow off at 50 lbs. absolute per square inch?

151. Explain the reasons which led to the abandonment of jet condensers for marine engines, and show how surface condensation has rendered possible the use of high-pressure steam in marine boilers.

152. Describe fully, and illustrate with sketches, a modern surface condenser for a marine engine, together with its air and circulating pumps.

153. A marine engine indicating 4,000 H.P. uses 17 pounds of steam per I.H.P. per hour, and expands down to 5 pounds absolute: what surface would you provide in the condenser; how much cooling water of initial temperature of 60° would be required per hour; and what should be the capacity of the air-pumps (single-acting), the engine running at 56 revolutions per minute?

154. Why must the capacity of the air-pump of a surface condenser be so largely in excess of the volume of the water into which the steam condenses per stroke?

155. How is the condition of the vacuum in a condenser recorded? and what is the relation between the vacuum as recorded and the absolute pressure in pounds per square inch?

156. What precautions must be adopted in making the tubes of surface condensers, so as to avoid the possibility of carrying over corrosive metallic salts into the boiler?

157. Make a sketch of any of the packings for condenser tubes in common use.

158. Describe a jet condenser for a high-speed stationary engine, and state how the use of a separate air-pump can be avoided.

159. An engine indicating 60 H.P. uses 20 pounds of steam per I.H.P. per hour, and expands down to 6 pounds absolute: how much injection water will be required per hour, the original temperature of which is 60°, the temperature of the hot well being 106°?

160. Make a sketch, and give a description, of an ejector condenser for a two-cylinder engine.

161. The metal of a cylinder is capable of rapidly receiving and transmitting heat: explain why this property is the cause of serious loss of efficiency in the expansive steam engine. How does it come to pass that the use of the steam-jacket greatly diminishes this loss of efficiency in spite of the fact that, to keep the cylinder always hot, steam is constantly being condensed in the jacket, the greater part of the heat thus liberated being uselessly transmitted to the exhaust.

162. What is the object of superheating steam? Is it possible to obtain any practical good effect in modern high-pressure engines by superheating the steam? Give your reasons for your reply.

163. Examine the effect of the dimensions of the cylinder, the initial pressure of the steam, and the rate of expansion on the initial condensation which takes place in the cylinder.

164. What are the four principal causes for the presence of water in the cylinders of steam engines?

165. What is the object of compounding or expanding the steam successively in two or more cylinders instead of in one? Why is it

that in modern marine engineering triple and quadruple expansive engines are now so largely used?

166. Illustrate by outline diagrams the principal methods of arranging the cylinders in ordinary and triple expansive engines.

167. A simple and a compound engine work at the same rate of expansion, and develope the same power. What is the size of the low-pressure cylinder of the compound compared with the cylinder of the simple engine? Give your reasons for your reply.

168. State the mechanical advantages of compound over simple expansive engines, and investigate the ratio of maximum to mean pressures, in (1) a pair of simple expansive engines, and (2) a compound engine of the same power, and working with the same initial pressure and the same ratio of expansion, on the supposition that the steam expands hyperbolically and that the effects of early release, compression, and clearance are neglected. The initial pressure is 115 lbs. absolute. The ratio of expansion = 12, the area of each of the high-pressure cylinders = A. The ratio of area of low to area of high-pressure cylinder in the compound engine = 4·5. The received pressure 24 lbs. per square inch.

169. Explain how in practice the powers developed in the two cylinders of a compound engine may be made approximately equal.

170. Make a sketch diagram illustrating the distribution of the steam in both cylinders of an ordinary two-cylinder receiver compound engine, choosing any symbols you like to represent the governing data. The steam in the large cylinder is supposed to be cut off before half stroke, and the expansion to take place hyperbolically. The effects of clearance, early release, and compression are to be neglected.

171. A triple expansive engine works at a consumption of 1·3 lb. of coal per I.H.P. per hour. The boilers evaporate 8 pounds of water per hour per pound of coal from the temperature of the feed 105°, and at the temperature of the initial pressure of the steam, viz. 165 lbs. above the atmosphere. (Corresponding temperature 366°.) What is the consumption of steam per horse-power per hour? What would it be if the engines were theoretically perfect and working between the above limits of temperature? What is the efficiency of the engine compared to a perfect engine? What is its absolute efficiency? What is the efficiency of the boiler compared to that of a perfect boiler which cools the products of combustion down to the temperature of the feed, the heat of combustion of one pound of coal being put down as 14,000 thermal units? Finally, what proportion of the total heat-supply is wasted by the boiler and what by the engine?

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