NEACT Southern Division Meeting
Steaming into the Future
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Historical Scientific Data Excerpts from SSHSA Archives
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TABLE 29

VARIATION IN CO_2 WITH DIFFERENT PERCENTAGES OF EXCESS AIR AND DIFFERENT FUELS

	Class of Fuel					
Constituent	Coal*	Wood*	Oil*	Natural Gas†	By-product Gas†	Blast Furnace Gas†
C	79.86	50.31	84.00	. . .	. . .	. . .
H_2	5.02	6.20	12.70	1.82	53.00	3.50
O_2	4.27	43.08	1.20	0.35	. . .	. . .
N_2	1.86	0.04	1.70	3.40	12.10	58.60
S	1.18	. . .	0.40	. . .	. . .	. . .
Ash	7.81	0.37	. . .	. . .	. . .	. . .
CO	. . .	. . .	. . .	0.45	6.00	25.40
CO_2	. . .	. . .	. . .	0.22	0.75	12.50
CH_4	. . .	. . .	. . .	93.33	28.15	. . .
C_2H_4	. . .	. . .	. . .	0.25	. . .	. . .
H_2S	. . .	. . .	. . .	0.18	. . .	. . .
Excess Air Per Cent	Percentage of CO_2 Corresponding to Different Amounts of Excess Air					
0	18.43	20.10	15.40	11.65	9.36	25.08
20	15.29	16.72	12.69	9.54	7.67	22.97
40	13.06	14.31	10.79	8.07	6.49	21.20
60	11.40	12.51	9.38	6.99	5.63	19.67
80	10.11	11.12	8.30	6.17	4.97	18.38
100	9.09	10.00	7.45	5.52	4.48	17.20

*Analysis by weight. †Analysis by volume.

TABLE 29A

TESTS OF BABCOCK & WILCOX MARINE BOILERS USING COAL FUEL

Date	August, 1922		June, 1910		
Location	S. S. "Crescent City"		U. S. S. "Wyoming" Test Boiler, Bayonne, N. J.		
Type of Babcock & Wilcox marine boiler	4-inch tube		2-inch tube		
Duration, hours	9	9	24.06	24	3
State of weather	Clear	Clear	Clear	Partly Clear	Clear
Type of draft	Natural	Natural	Natural	Forced	Forced
Method of firing	Hand	Hand	Hand	Hand	Hand
Kind of fuel	Semi-Bituminous (Detour)		Pocahontas, Hand Picked		
Total heating surface, square feet	5366	5366	2571.39	2571.39	2571.39
Grate surface, square feet	140	140	57.89	57.89	57.89
AVERAGE PRESSURES					
Boiler steam pressure by gauge, pounds	...	...	202.0	201.6	200.4
Starboard	234.4	236.4	...	...	...
Port	233.8	236.8	...	...	...
Barometer	29.22	29.26	30.06	29.83	29.62
AVERAGE TEMPERATURES—DEGREES FAHRENHEIT					
Fireroom	85.23	90.7	93.7	94.0	106.0
Hotwell	124.0	124.0	...	...	...
Feed water leaving heater	184.33	195.4	211.6	204.1	194.4
Boiler exit gases at uptake	532.0	538.0	491.0	628.0	659.0
FUEL					
Weight of coal as fired, pounds	26691.0	27598.5	21200.0	57700.0	12200.0
Moisture in coal, per cent	2.49	2.30	0.88	1.06	0.75
Weight of dry coal consumed, pounds	26043.4	26963.7	21013.0	57088.0	12108.0
Weight of ash and refuse, pounds	2000.0	1945.5	1261.0	2477.0	1035.0
Weight of combustible consumed, pounds	24043.4	25018.2	19752.0	54611.0	11073.0
Refuse in dry coal, per cent	7.68	7.21	6.00	4.34	8.55
FUEL PER HOUR					
Coal consumed per hour, pounds	2965.6	3049.6	881.0	2404.0	4066.0
Dry coal consumed per hour, pounds	2893.5	2996.0	873.0	2379.0	4036.0
Combustible consumed per hour, pounds	2669.6	2780.0	821.0	2275.0	3691.0
Coal consumed per hour per square foot G. S., pounds	21.18	21.78	15.22	41.53	70.24
Dry coal consumed per hour per square foot G. S., pounds	20.66	21.38	15.08	41.10	69.72
Combustible consumed per hour per square foot G. S., pounds	19.08	19.83	14.18	39.30	63.77
Coal per hour per square foot H. S., pounds	.55	.57	.343	.935	1.581
Dry coal per hour per square foot H. S., pounds	.54	.55	.340	.925	1.569
Combustible per hour per square foot H. S., pounds	.50	.52	.319	.885	1.435

TESTS OF BABCOCK & WILCOX MARINE BOILERS USING COAL FUEL—Continued

Water										
Total weight of water to boilers, pounds	242711.		246743.		228095.		612698.		106504.	
Factor of evaporation	1.0812		1.0698		1.052		1.060		1.069	
Total evaporation from and at 212° Fahrenheit, pounds	262419.		263965.7		239956.		649460.		113853.	
Water Per Hour										
Water evaporated per hour, pounds	26967.9		27415.9		9480.		25530.		35501.	
Equivalent evaporation from and at 212° F., pounds	29157.7		29329.5		9974.		27060.		37951.	
Equivalent evaporation from and at 212° F. per sq. ft. G. S., pounds	208.27		209.49		172.		468.		656.	
Equivalent evaporation from and at 212° F. per sq. ft. H. S., pounds	5.44		5.47		3.88		10.52		14.76	
Economic Results										
Water actually evaporated per pound of coal as fired, pounds	9.09		8.99		10.76		10.62		8.73	
Equivalent evaporation from and at 212° F. per lb. of coal as fired, lbs.	9.83		9.62		11.32		11.26		9.33	
Equivalent evaporation from and at 212° F. per lb. of dry coal, lbs.	10.08		9.78		11.42		11.38		9.40	
Equivalent evaporation from and at 212° F. per lb. of combustible, lbs.	10.92		10.54		12.15		11.89		10.28	
Efficiency: Boiler including grate	71.31		71.37		72.55		72.28		59.73	
Flue Gas Analysis—Top 3rd Pass										
Carbon dioxide (CO_2)	12.50		12.28		13.20		13.60		11.60	
Oxygen (O_2)	5.48		6.28		4.20		3.90		5.07	
Carbon monoxide (CO)	0.00		0.00		0.50		0.80		1.09	
Nitrogen (N_2) (by difference)	82.02		81.44		82.10		81.70		82.24	
Ultimate Analysis of Dry Coal—Per Cent										
Carbon	75.88		75.88		87.51		87.51		87.51	
Hydrogen	5.41		5.41		4.74		4.74		4.74	
Oxygen and nitrogen	11.74		11.74		3.67		3.67		3.67	
Ash	6.45		6.45		3.38		3.38		3.38	
Sulphur	.52		.52		.70		.70		.70	
Heat value per pound of dry coal, B. t. u.	13718.		13297.		15273.		15273.		15273.	
Combustible in ash, per cent	38.86		48.10		31.93		60.99		70.72	
Heat Balance	B. t. u.	Per Cent	B. t. u.	Per Cent	B. t. u.	Per Cent	B. t. u.	Per Cent	B. t. u.	Per Cent
Heat absorbed by boiler	9779.	71.31	9491.	71.37	11081.00	72.55	11040.00	72.28	9122.00	59.73
Loss due to moisture in fuel	30.	.22	29.	.22	10.84	.07	13.72	.09	9.71	.06
Loss due to moisture formed by burning of hydrogen	607.	4.42	606.	4.55	521.00	3.41	547.00	3.58	548.00	3.59
Loss due to heat carried away in dry gases	1661.	12.10	1669.	12.56	1503.00	9.84	1909.00	12.50	2134.00	13.97
Loss due to incomplete combustion of carbon	0.	0.00	0.	0.00	317.00	2.08	479.00	3.14	711.00	4.65
Loss due to unconsumed carbon in ash	435.	3.17	507.	3.82	280.00	1.83	386.00	2.53	883.00	5.78
Loss due to radiation and unaccounted losses	1206.	8.78	995.	7.48	1560.16	10.22	898.28	5.88	1865.29	12.22
Total	13718.	100.00	13297.	100.00	15273.00	100.00	15273.00	100.00	15273.00	100.00

For the reactions to be accomplished in this table, it is necessary that the amount of oxygen supplied for combustion be the exact amount required and be wholly used. Such a condition necessitates a distinction between perfect and complete combustion. Combustion may be complete when an excess of oxygen over that actually required is supplied, such excess appearing as unused oxygen in the products of combustion. Combustion is only perfect when complete without the presence of oxygen in the products resulting from such combustion. An example of combustion that is neither complete nor perfect is that of carbon to carbon monoxide. Since carbon monoxide is capable of a further combination with oxygen to form carbon dioxide, combustion is obviously incomplete. Combustion that is complete but not perfect is discussed hereafter under the heading of excess air.

TABLE 24

CHEMICAL REACTIONS OF COMBUSTION

Combustible Substance	Reaction
Carbon (to CO)	$2C + O_2 = 2CO$
Carbon (to CO_2)	$2C + 2O_2 = 2CO_2$
Carbon Monoxide	$2CO + O_2 = 2CO_2$
Hydrogen	$2H_2 + O_2 = 2H_2O$
Sulphur (to SO_2)	$S + O_2 = SO_2$
Sulphur (to SO_3)	$2S + 3O_2 = 2SO_3$
Methane	$CH_4 + 2O_2 = CO_2 + 2H_2O$
Acetylene	$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O$
Ethylene	$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$
Ethane	$2C_2H_6 + 7O_2 = 4CO_2 + 6H_2O$
Hydrogen Sulphide	$2H_2S + 3O_2 = 2H_2O + 2SO_2$

IGNITION TEMPERATURE.—While, as stated, the speed of combustion is primarily dependent upon the affinity of the combustible for combination with oxygen, it is also dependent upon the conditions under which combustion takes place, and the chief of such conditions is that of temperature. Introducing a combustible into the presence of oxygen does not of necessity result in combustion.

TABLE 25

IGNITION TEMPERATURES

Combustible Substance	Molecular Symbol	Ignition Temperature Degrees Fahrenheit
Sulphur	S_2	470
Fixed Carbon—Bituminous Coal	...	766
Fixed Carbon—Semi-bituminous Coal	...	870
Fixed Carbon—Anthracite Coal	...	925
Acetylene	C_2H_2	900
Ethane	C_2H_6	1000
Ethylene	C_2H_4	1022
Hydrogen	H_2	1130
Methane	CH_4	1202
Carbon Monoxide	CO	1210

Every combustible substance has a temperature called its "ignition temperature," to which it must be brought before it will unite with oxygen in chemical combination, and below which such combination will not take place. This ignition temperature must exist with oxygen present or no combustion will occur. The ignition temperature of various fuels and of the combustible constituents of such fuels is given in Table 25.

The temperature of ignition of the gases of a coal varies and is higher than the ignition temperature of the fixed carbon constituent. The ignition temperature of coal is that of its fixed carbon content, the gaseous constituents being ordinarily distilled off, though not ignited, before this temperature is reached.

iron, it then develops greater strength therein. However, to insure this, correct proportions must be maintained. Increasing the carbon content up to a certain maximum augments the strength. But beyond this maximum, the strength decreases with the increase of carbon content.

EXAMPLE.—Mild steel that contains 0.1 per cent. of carbon has a tensile strength of about 50,000 lb. per sq. in. With twelve times this quantity or 1.2 per cent. of carbon, the tenacity, if tempered, is increased to nearly 140,000 lb. per sq. in., which is probably the upper limit for carbon steel. Increasing the percentage of carbon above this value results in a proportionate drop in the tenacity. With 2.0 per cent. its unit strength is about 90,000 lb. Further gradual increase in the carbon component causes the material to become brittle.

123. Carbon contributes to the hardness of boiler-plate. The hardness increases with the increase of carbon content. This quality is especially desirable in flues and tubes and in the sheets of fire-boxes and combustion chambers. In these locations the metal must withstand the abrading action of the cinder-laden gas currents. There is, however, a degree of hardness which marks the maximum limit. If an attempt is made to obtain harder metal, other very necessary qualities of good boiler-plate will be sacrificed.

124. Excessive carbon tends to destroy ductility of the material. Its malleability may also be thereby impaired to a ruinous extent. Likewise, a plate containing an excess of carbon will be lacking in toughness. Sufficient carbon to make the plate quite hard will also make it brittle.

125. Good boiler-plate steel contains just enough carbon to insure proper melting in the furnace. This consideration amply gages the amount of carbon necessary to produce a satisfactory blending of the desired properties. Generally, the quantity of carbon is less than 0.25 per cent. With this small carbon content, practically all liability of the material to harden and crack under a stress, which is caused by a sudden and wide change of temperature, is eliminated.

126. Phosphorus is undesirable in boiler-plate steel.—Although its presence makes a steel strong and hard, and thus would seem desirable, these qualities are secured best through the medium of carbon. The reason is that phosphorus tends to make the material cold-short, that is brittle, when cold. Steel containing much phosphorous is particularly weak against shock and vibratory stresses. On this account, it may be considered the most harmful of the ingredients in steel boiler-plate. It is for this reason that Bessemer process steels are undesirable for boiler-making. The method does not remove from the steel the phosphorus, which was originally in the pig iron.

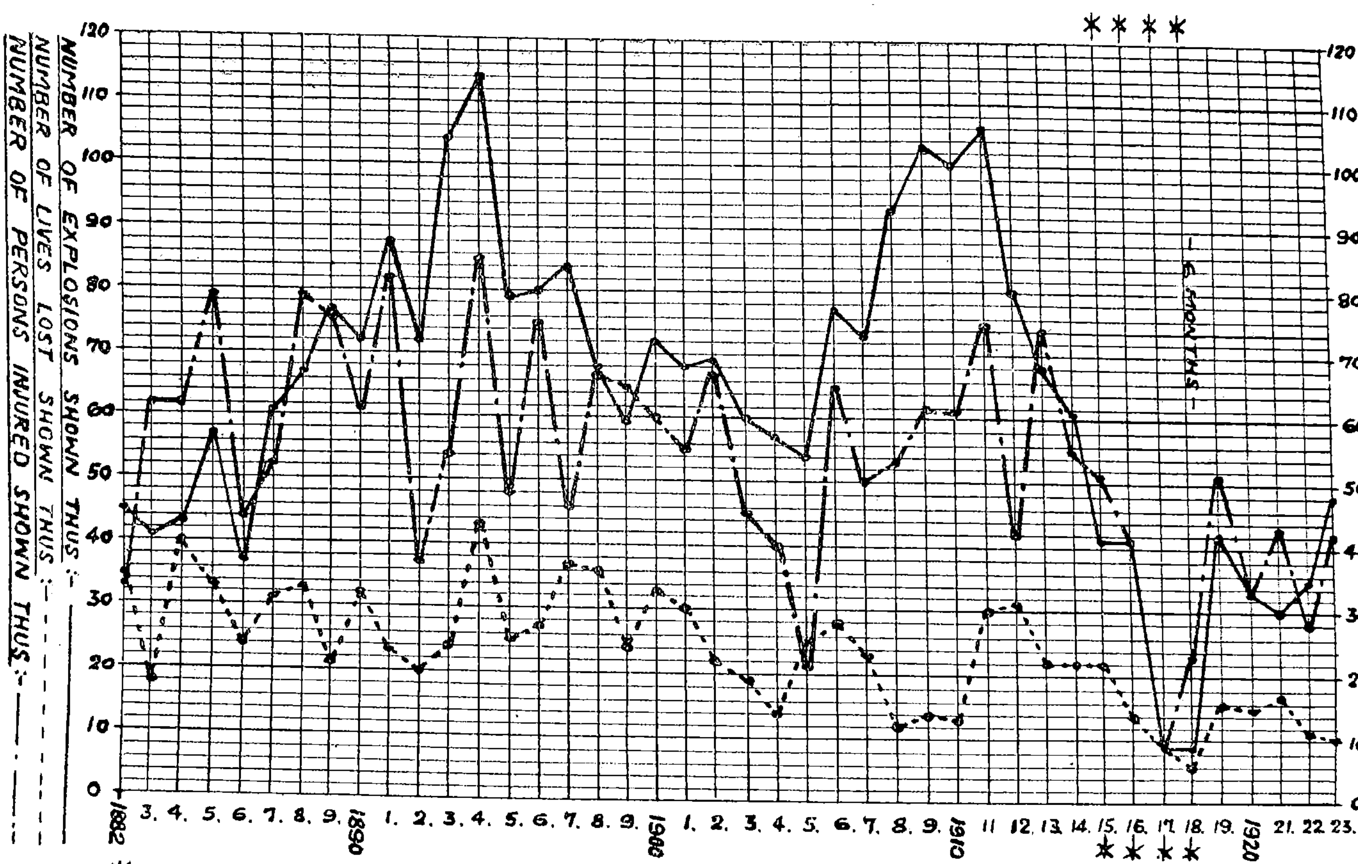
127. Sulphur is detrimental to steel in various ways. Its principal effect is to impair the tenacity and ductility of the plate and to make it hot-short, or brittle and difficult to work when hot.

128. Silicon In Mild Steel Makes It Harder.—There is but a small quantity present. Even this increases the hardness slightly, but without diminishing toughness or ductility and without affecting appreciably its tensile strength. This might, therefore, be regarded as a beneficial ingredient.

129. Manganese In Mild Steel Is A Hardening Agent.—Steel which contains a considerable proportion of this element acquires a peculiar brittleness and hardness which makes it difficult to cut with machine tools. Manganese has, however, a neutralizing effect on sulphur. It combines with sulphur in the steel to form manganese sulphide. This component is less objectionable than the iron sulphide that would otherwise be formed. The presence of manganese might, therefore, be regarded as advantageous.

130. Chemical Properties For Steels Are Specified By The Boiler Codes.—The standard rules, those of the *American Society of Mechanical Engineers* for example, stipulate certain chemical properties for steels of various grades for plates, stays, rivets, and the like. (Table 131.)

131. Table Showing the Uses, Chemical Properties and Physical Properties of the Various Grades of Steel and Iron as Specified in the A.S.M.E. Code, 1918.



* OWING TO PRESSURE ARISING OUT OF THE WAR, INQUIRIES WERE NOT HELD IN ALL CASES IN THESE YEARS, AND IN 1917-18 ONLY VERY SERIOUS AND IMPORTANT CASES COULD BE DEALT WITH.

Fig. 1.—Explosion Chart.

The same method may be used to find the lower heating value per pound when the weight composition is given. The method, however, does not apply in the case of the higher heating value.

EXERCISES

The following table gives the approximate composition by volume of certain fuel gases.

	H_2	CO	CH_4	C_2H_4	O_2	CO_2	N_2
1. Blast furnace gas.......	0.04	0.27	....	....	....	0.10	0.59
2. Producer gas..........	0.15	0.22	0.03	....	....	0.09	0.51
3. Water gas.............	0.50	0.45	....	....	....	0.03	0.02
4. Carbureted water gas..	0.30	0.27	0.25	0.15	....	0.01	0.02
5. Natural gas...........	0.02	0.01	0.93	....	0.005	0.005	0.03

1. Find the composition by weight of each of these gases.

2. For each of the gases find the volume of air required for the combustion of 1 cu. ft. of the gas.

Ans. { 2. 1.176 cu. ft.; 5. 8.98 cu. ft.

3. Using 15 per cent. excess air, make up schedules of the mixture of fuel and air and of the mixture of products. Show the composition of each mixture in mols and in pounds.

4. From these schedules calculate the constants B_m of the original mixtures and the constants B_p of the mixtures of the products.

Ans. { 1. $B_m = 53.82$, $B_p = 49.33$; 3. $B_m = 61.40$, $B_p = 53.35$; 4. $B_m = 56.42$, $B_p = 54.36$

5. Derive expressions for the specific heats c_p and c_v per pound for all the mixtures.

6. Find the lower heating value of each gas per cubic foot under standard conditions.

Ans. { 1. 98 B. t. u.; 2. 140 B. t. u.; 3. 285 B. t. u.; 4. 625 B. t. u.; 5. 858 B. t. u.

7. Find the contraction in volume of each gas when burned with 15 per cent excess air.

8. From the composition of the mixture of products determine in each case the partial pressure of the H_2O constituent, assuming that the pressure of the mixture is 14.7 lb. per sq. in. Determine the temperature at which condensation of H_2O begins.

9. From the general expression for the heat of combustion H_p show that H_p has a maximum or minimum value at some temperature. Derive an expression from which the temperature at which the maximum or minimum occurs may be calculated.

ishment from time to time. Indeed it does, for being a contact process, the porosity of the zeolite is important. As the pores clog, it loses efficiency till replacement is necessary. For this reason turbid cloudy waters must be filtered before softening.

Zeolite systems are elaborate and expensive. For this reason they are calculated "close", often incapable of taking care of full demands, especially as the efficiency of the zeolite drops, and though they are capable of discharging "zero" water, frequently fail to do this.

Because of their expense, very hard water cannot be handled cheaply. It must first be softened by lime-soda, filtered, and then further softened - if necessary with zeolite. They likewise frequently discharge water with residual hardness and fail to consider the soluble salts liberated and the corrosiveness of the water; hence supplementary treatment is indicated despite their use when the object is water for steam generation. It can be said, however, that where the object is soft water for process, there is nothing better than a properly operated zeolite softener.

Boiler Compounds

It is not possible to consider these in all their many forms and variations. The more common ingredients and their merits, if any, can be briefly considered.

Caustic Soda - (NaOH):- This is good for precipitating magnesium compounds and raising the alkalinity. The evil is that it fails to benefit the calcium and promiscuous use leads to excessive alkalinity and embrittlement.

Soda Ash - (Na_2CO_3):- This would be better in general use were it not for the fact that it decomposes to caustic soda and has its failings as a consequence. Under limited pressures it serves some good purpose.

Sodium Silicate (indefinite formula):- This is possessed of no virtue whatsoever, adding to rather than alleviating the evils calling for correction. With calcium and magnesium it forms hard, dense, firmly adhering deposits of the corresponding silicate, not unlike these deposits found in nature in rock deposits. The claim of being a metal treatment is more imaginary than real.

Sodium Aluminate (formula indefinite):- Forms a floc-like combination with calcium and magnesium compounds in intimate mixture with hydrated alumina - a coagulating, colloidal floc. Being hydrated, it loses water and reverts to the dehydrated form of A $_2O_3$ (aluminum oxide or bauxite).

Tri Sodium Phosphate (Na_3PO_4):- Best all around precipitant. Tends to deposit in feed lines. orks very well with supplemental colloidal coagulant.

Di Sodium Phosphate (Na_2HPO_4):- Forms Na_3PO_4 with alkali. Has all the properties of Na_3PO_4 to which it should be converted either with alkali in the natural supply or purposely added with treatment.

Mono Sodium Phosphate (NaH_2PO_4):- Same as disodium, but demands more alkali.

TABLE "A"

SOLUBLE		INSOLUBLE		INTERMEDIATE	
Compound	Solubility Pts. per 100	Compound	Solubility Pts. per 100	Compound	Solubility Pts. per 100
$MgCl_2$	53.	$Mg(OH)_2$	.0009	$Ca(OH)_2$	.185
$MgSO_4$	26.	$MgCO_3$	.01		
$CaCl_2$	60.	$MgSiO_3$	not recorded		
$Ca(HCO_3)_2$	indefinite	$CaCO_3$	.0014		
$Mg(HCO_3)_2$	"	$CaSiO_3$	.0095		
KCI	27.6	$Fe(OH)_3$	.00067		
NaCI	35.7	Al_2O_3	.00015		
$CaSO_4$	.30				
NaOH	42.	$Fe(OH)_2$	.00067		
Na_2CO_3	7.10				
K_2SO_4	7.35				
Na_2SO_4	48.8				

TABLE "B"

Compound	Solubility Cold	Solubility Hot	Nature of Solubility	Nature of Deposit
$CaSO_4$	.30	.16	-	adhering
$CaCl_2$	60.	159.	+	non scale forming
$CaCO_3$	.0014	.0019	+	non adhering
$Ca(OH)_2$	.185	.077	-	adhering
$MgSO_4$	26.	74.	+	non scale forming
$MgCl_2$	53.	73.	+	non scale forming
$MgCO_3$	.01			non adhering
$Mg(OH)_2$	.0009	.004	+	non adhering

GRAPHIC ILLUSTRATION OF SOLUBILITY CHARACTERISTICS

"a" shows decreasing solubility with increase in temperature, or negative character

"b" shows increasing solubility with increase in temperature, or positive character