

Maccabee revival. It is this national feeling that, claiming a leader against the Romans as well as deliverance from the Sadducee aristocracy, again sets the idea of the kingship rather than that of resurrection and individual retribution in the central place which it had lost since the captivity. Henceforward the doctrine of the Messiah is at once the centre of popular hope and the object of theological culture. The New Testament is the best evidence of its influence on the masses (see especially Matt. xxi. 9); and the exegesis of the Targums, which in its beginnings doubtless reaches back before the time of Christ, shows how it was fostered by the Rabbins and preached in the synagogues.<sup>1</sup> Its diffusion far beyond Palestine, and in circles least accessible to such ideas; is proved by the fact that Philo himself (*De Præm. et Pœn.*, § 16) gives a Messianic interpretation of Num. xxiv. 27 (LXX.). It must not indeed be supposed that the doctrine was as yet the undisputed part of Hebrew faith which it became when the fall of the state and the antithesis to Christianity threw all Jewish thought into the lines of the Pharisees. It has, for example, no place in the *Assumptio Mosis* or the *Book of Jubilees*. But, as the fatal struggle with Rome became more and more imminent, the eschatological hopes which increasingly absorbed the Hebrew mind all group themselves round the person of the Messiah. In the later parts of the *Book of Enoch* (the "symbols" of chaps. xlv. sq.) the judgment day of the Messiah (identified with Daniel's "Son of Man") stands in the forefront of the eschatological picture. Josephus (*B. J.* vi. 5, § 4) testifies that the belief in the immediate appearance of the Messianic king gave the chief impulse to the war that ended in the destruction of the Jewish state; after the fall of the temple the last apocalypses (*Baruch*, 4 *Ezra*) still loudly proclaim the near victory of the God-sent king; and Bar Cochebas, the leader of the revolt against Hadrian, was actually greeted as the Messiah by Rabbi Akiba (comp. Luke xxi. 8). These hopes were again quenched in blood; the political idea of the Messiah, the restorer of the Jewish state, still finds utterance in the daily prayer of every Jew (the *Sh'mônê Ešrê*), and is enshrined in the system of Rabbinical theology; but its historical significance was buried in the ruins of Jerusalem.<sup>2</sup>

But the proof written in fire and blood on the fair face of Palestine that the true kingdom of God could not be realized in the forms of an earthly state, and under the limitations of national particularism, was not the final refutation of the hope of the Old Testament. Amidst the last convulsions of political Judaism a new and spiritual conception of the kingdom of God, of salvation, and of the Saviour of God's anointing, had shaped itself through the preaching, the death, and the resurrection of Jesus of Nazareth. As applied to Jesus the name of Messiah lost all its political and national significance, for His victory over the world, whereby He approved himself the true captain of salvation, was consummated, not amidst the flash of earthly swords, or the lurid glare of the lightnings of Elias,

<sup>1</sup> The Targumic passages that speak of the Messiah are registered by Buxtorf, *Lex. Chald.*, s. v.

<sup>2</sup> False Messiahs have continued from time to time to appear among the Jews. Such was Serenus of Syria (circa 720 A.D.). Soon after, Messianic hopes were active at the time of the fall of the Omayyads, and led to a serious rising under Abu Isa of Ispahan, who called himself forerunner of the Messiah. The false Messiah David Alroi (Alroy) appeared among the warlike Jews in Azerbaijan in the middle of the 12th century. The Messianic claims of Abraham Abulafia of Saragossa (born 1240) had a cabalistic basis, and the same studies encouraged the wildest hopes at a later time. Thus Abarbanel calculated the coming of the Messiah for 1503 A.D.; the year 1500 was in many places observed as a preparatory season of penance; and throughout the 16th century the Jews were much stirred and more than one false Messiah appeared. For the false Messiah Sabbathai, see vol. xiii. p. 681.

but in the atoning death through which He entered into the heavenly glory. Between the Messiah of the Jews and the Son of Man who came not to be ministered to but to minister, and to give his life a ransom for many, there was on the surface little resemblance; and from their standpoint the Pharisees reasoned not amiss that the marks of the Messiah were conspicuously absent from this Christ. But when we look at the deeper side of the Messianic conception in the *Psalter of Solomon*, at the heartfelt longing for a leader in the way of righteousness and acceptance with God which underlies the aspirations after political deliverance, we see that it was in no mere spirit of accommodation to prevailing language that Jesus did not disdain the name in which all the hopes of the Old Testament were gathered up. The kingdom of God is the centre of all spiritual faith, and the perception that that kingdom can never be realized without a personal centre, a representative of God with man and man with God, was the thought, reaching far beyond the narrow range of Pharisaic legalism, which was the last lesson of the vicissitudes of the Old Testament dispensation, the spiritual truth that lay beneath that last movement of Judaism which concentrated the hope of Israel in the person of the anointed of Jehovah.

It would carry us too far to consider in this place the details of the Jewish conception of the Messiah and the Messianic times as they appear in the later apocalypses or in Rabbinical theology. See for the former the excellent summary of Schürer, *NTliche Zeitgeschichte*, §§ 28, 29 (Leipzig, 1874), and for the latter, besides the older books catalogued by Schürer (of which Schoettgen, *Horæ*, 1742, and Bertholdt, *Christologia Judæorum*, 1811, may be specially named), Weber, *Altsynagogale Theologie* (Leipzig, 1880). For the whole subject see also Drummond, *The Jewish Messiah* (London, 1877), and Kuenen, *Religion of Israel*, chap. xii. For the Messianic hopes of the Pharisees and the *Psalter of Solomon* see especially Wellhausen, *Pharisæer und Sadducæer* (Greifswald, 1874). In its ultimate form the Messianic hope of the Jews is the centre of the whole eschatology, embracing the doctrine of the last troubles of Israel (called by the Rabbins the "birth pangs of the Messiah"), the appearing of the anointed king, the annihilation of the hostile enemy, the return of the dispersed of Israel, the glory and world-sovereignty of the elect, the new world, the resurrection of the dead, and the last judgment. But even the final form of Jewish theology shows much vacillation as to these details, especially as regards their sequence and mutual relation, thus betraying the inadequacy of the harmonistic method by which they were derived from the Old Testament and the stormy excitement in which the Messianic idea was developed. It is, for example, an open question among the Rabbins whether the days of the Messiah belong to the old or to the new world (הַיְיָוִם הַזֶּה or הַיְיָוִם הַבָּא), whether the resurrection embraces all men or only the righteous, whether it precedes or follows the Messianic age. Compare MILLENNIUM.

We must also pass over the very important questions that arise as to the gradual extrication of the New Testament idea of the Christ from the elements of Jewish political doctrine which had so strong a hold of many of the first disciples—the relation, for example, of the New Testament Apocalypse to contemporary Jewish thought. A word, however, is necessary as to the Rabbinical doctrine of the Messiah who suffers and dies for Israel, the Messiah son of Joseph or son of Ephraim, who in Jewish theology is distinguished from and subordinate to the victorious son of David. The developed form of this idea is almost certainly a product of the polemic with Christianity, in which the Rabbins were hard pressed by arguments from passages (especially Isa. liii.) which their own exegesis admitted to be Messianic, though it did not accept the Christian inferences as to the atoning death of the Messianic king. That the Jews in the time of Christ believed in a suffering and atoning Messiah is, to say the least, unproved and highly improbable. See, besides the books above cited, De Wette, *Opuscula*; Wünsche, *Die Leiden des Messias*, 1870. The opposite argument of King, *The Yalkut on Zechariah* (Cambridge, 1882), App. A, does not really prove more than that the doctrine of the Messiah Ben Joseph found points of attachment in older thought. (W. R. S.)

MESSINA, a city and seaport at the north-east corner of Sicily, capital of the province of the same name,<sup>3</sup> is

<sup>3</sup> The province occupies the north-east corner of the island, and is 60 miles in length by 30 in breadth. It is chiefly occupied with mountain ranges and valleys; there are few plains. The largest river is the

situated on the Straits of Messina (at this point about 4 miles wide), 8 miles north-west of Reggio and 130 miles east by north of Palermo, in 38° 15' N. lat., 15° 30' E. long. The town is built between the sea and a range of sharp and rugged hills, called the Dinnamare, 3707 feet at their highest point. It runs in a semicircle round the harbour, and presents a picturesque appearance from the sea, as the houses rise in tiers upon the slope of a hill, and behind are the wooded mountains.

Messina is the second town of Sicily in importance and in size. Its population was 97,074 in 1850, 111,854 in 1871, and 126,497 in 1881. It is an archiepiscopal see, and has a university, founded by the Jesuits in 1548, with a public library of 56,000 volumes.

The excellence of its harbour makes Messina an important trading town. The harbour is formed by a tongue of low land which runs out from the shore in the form of a sickle, and encloses a round basin, open to the north only, where the entrance channel is about 500 yards wide. This basin is 1½ miles in circumference, and is of such depth that the largest vessels are able to use it. It is estimated that 1300 steamers, with a total of 1,000,000 tons burthen, and 9000 sailing ships, with a total of 500,000 tons burthen, enter the port yearly. The exports of Messina consist chiefly of oranges, lemons, raisins, wine, oil, liquorice, and hides. There is no prominent manufacture; but silk stuffs are made in considerable quantities. Many of the inhabitants are engaged in fishing, chiefly for tunny. Sword-fish also are captured with the harpoon in the Straits during July and August. Coral fishery is a trade of the people. The hills behind Messina produce a strong dark wine, inferior to that which is made in other parts of the island.

Messina has few buildings of importance or antiquity. The sieges and earthquakes from which the town has suffered destroyed most of its monuments. After the great earthquake in 1783 the city was almost entirely rebuilt. The cathedral, the principal building, is a church of the Norman period. It was begun in 1098 by Count Roger I., and finished by his son Roger II. The church is in the form of a Latin cross, 305 feet long and 145 feet wide in the transepts. The lower half of the façade is encrusted with slabs of red and white marble. It has three Gothic portals, with pointed arches and rich ornamentation, belonging to the period of the Anjou dynasty. The nave contains twenty-six columns of Egyptian granite, said to have been brought from an ancient temple of Poseidon which stood near the Faro. The mosaics of the apses date from the year 1330. In the choir are the sarcophagi of the emperor Conrad IV. (d. 1254), of Alphonso the Generous (d. 1458), and of Antonia, widow of Frederick III. of Aragon. In 1254 the cathedral was seriously damaged by fire; in 1559 the campanile was burned down; in 1783 the earthquake overthrew the campanile and the transept. The building therefore offers a mixture of styles,—first Norman, then Gothic, then Early Renaissance, finally Barocco and Modern Gothic.

The history of Messina begins very early. It is said to have been founded, on the site of a more ancient Sicilian town, by pirates from Cumæ, in 732 B.C. It took its earlier name of Zancle (a sickle) from the shape of its harbour. The number of its inhabitants was increased by an influx of Chalcidians under Cratemenes; and in 649 B.C. the town was sufficiently prosperous and populous to establish a colony at Himera. The Samians occupied Zancle for a short time after Miletus had been captured by the Persians in 494 B.C. In the following year the city fell into the hands of Anaxilas, tyrant of Rhegium, who introduced a population of Messenians, from Messenia in the Peloponnus; and they changed the name of the place to Messana, in the Doric pronunciation, to

Alcantara. The chief towns are Messina, Castrolibate, Mistretta, Patti, and Milazzo. The population in 1854 was 380,279, in 1871 420,649, and in 1881 467,233.

remind them of their fatherland. The sons of Anaxilas were expelled from the government of Messina in 466 B.C., and a republic established; and this government was continued until Messina fell into the hands of the Carthaginians during their wars with Dionysius the elder of Syracuse (396 B.C.). The Carthaginians destroyed the city; but Dionysius recaptured and rebuilt it. During the next fifty years Messina changed masters several times, till Timoleon finally expelled the Carthaginians in 343 B.C. In the wars between Agathocles of Syracuse and Carthage, Messina took the side of the Carthaginians. Agathocles's mercenaries, the Mamertines, treacherously seized the town in 288 B.C. and held it. They came to war with Hiero II. of Syracuse, after Agathocles's death; and Hiero's allies, the Carthaginians, helped him to reduce Messina. The Mamertines appealed for help to Rome, which was granted, and this led to a collision between Rome and Carthage, which ended in the First Punic War. At the close of that war, in 241 B.C., Messina became a possession of the Romans. During the civil wars which followed the death of Julius Cæsar, Messina held with Sextus Pompeius; and in 35 B.C. it was sacked by Octavian's troops. After Octavian's proclamation as emperor he founded a colony here; and Messina continued to flourish as a trading port. In the division of the Roman empire it belonged to the emperors of the East; and in 547 A.D. Belisarius collected his fleet here before crossing into Calabria. The Saracens took the city in 831 A.D.; and in 1061 it was the first permanent conquest made in Sicily, by the Normans under Roger d'Hauteville. In 1190 Richard Cœur de Lion with his crusaders passed six months in Messina. He fell out with Tancred, the last of the Hauteville dynasty, and sacked the town. In 1194 the city, with the rest of Sicily, passed to the house of Hohenstaufen under the emperor Henry VI., who died there in 1197. At the time of the Sicilian Vespers (1282), which drove the French out of Sicily, Messina bravely defended itself against Charles of Anjou, and repulsed his attack. Peter I. of Aragon, through his commander Ruggiero di Loria, defeated the French off the Faro; and from 1282 to 1713 Messina remained a possession of the Spanish royal house. In 1571 the fleet fitted out by the Holy League against the Turk assembled at Messina, and in the same year its commander, Don John of Austria, celebrated a triumph in the Piazza dell' Annunziata. For one hundred years, thanks to the favours and the concessions of Charles V., Messina enjoyed great prosperity. But the internal quarrels between the Merli, or aristocratic faction, and the Malvezzi, or democratic faction, fomented as they were by the Spaniards, helped to ruin the city (1671-78). The Messinians suspected the Spanish court of a desire to destroy the ancient senatorial constitution of the city, and sent to France to ask the aid of Louis XIV. in their resistance. Louis despatched a fleet into Sicilian waters, and the French occupied the city. The Spaniards replied by appealing to Holland, who sent a fleet under Ruyter into the Mediterranean. The French admiral, Duquesne, defeated the combined fleet of Spain and Holland, but, notwithstanding this victory, the French suddenly abandoned Messina in 1678, and the Spanish occupied the town once more. The senate was suppressed, and Messina lost its privileges. This was fatal to the importance of the city, and it never recovered. In 1743 the plague carried off 40,000 inhabitants. The city was partially destroyed by earthquake in 1783. During the revolution of 1848 against the Bourbons of Naples, Messina was bombarded for three consecutive days. In 1854 the deaths from cholera numbered about 15,000. Garibaldi landed in Sicily in 1860, and Messina was the last city in the island taken from the Bourbons and made a part of united Italy under Victor Emmanuel.

Messina was the birthplace of the following celebrated men: Dicaearchus, the historian (cir. 322 B.C.); Aristocles, the Peripatetic; Euhemerus, the rationalist (cir. 316 B.C.); Stefano Protonotario, Mazzeo di Riccio, and Tommaso di Sasso, poets of the court of Frederick II. (1250 A.D.); and Antonello da Messina, the painter (1447-99), five of whose works are preserved in the university gallery. During the 15th century the grammarian Constantine Lascaris taught in Messina; and Bessarion was for a time archimandrite there.

METALLURGY, a branch of applied science whose object is to describe and scientifically criticize the methods used industrially for the extraction of metals from their ores. Of the large number of metals enumerated in the handbooks of chemistry, the vast majority, of course, lie outside its range; but it is perhaps as well for us to point out that in metallurgic discussions even the term "metallic," as applied to compounds, has a restricted meaning, being exclusive of all the light metals, although one of these, namely aluminium, is being manufactured industrially. The following table enumerates in the order of their importance the metals which our subject at present

is understood to include; the second column in each case gives the chemical characters of the native compounds utilized, italics indicating ores of subordinate importance. The term "oxide" must be understood to include carbonate, hydrate, and occasionally (when marked in the table with \*) silicate.

Metal.	Character of Ores.
Iron	Oxides, sulphide.
Copper	Complex sulphides, also oxides, metal.
Silver	Sulphide and reguline metal chloride.
Gold	Reguline metal.
Lead	Sulphide and basic-carbonate, sulphate, &c.
Zinc	Sulphide, oxide.*
Tin	Oxide.
Mercury	Sulphide, reguline metal.
Antimony	Sulphide.
Bismuth	Reguline metal.
Nickel and cobalt	Arsenides.

Platinum and platinum metals...Reguline.  
Aluminium.....Oxide,\* sodio-fluoride.

We have separated the last two from the rest because the methods used for their preparation are more of the character of laboratory operations, and because we do not mean to include these in our general exposition of metallurgic principles. The history of metallurgy, up to the most recent times, is obscure. It is only since about the beginning of this century that the art has come to be at all scientifically criticized; and in the case of the most important processes all that science has been able to do has been merely to put her stamp upon what experience has long found to be right. Great and brilliantly successful scientific efforts in the synthetic line are not wanting, but they all belong to recent times. Science, by its very nature, aims at publicity; empiricism at all times has done the reverse; hence a history of the development of the art of metallurgy does not and cannot exist. A few historical notes on the discovery of certain of the useful metals are given in the introduction to METALS (q.v.).

**General Sequence of Operations.**—Occasionally metallic ores present themselves in the shape of practically pure compact masses, from which the accompanying matrix or "gangue" can be detached by hand and hammer. But this is a rare exception. In most cases the "ore," as it comes out of the mine, is simply a mixture of ore proper and gangue, in which the latter not unfrequently predominates so much that it is not the gangue but the ore that really occupies the position of what the chemist would call the impurity. Hence, in general, it is necessary, or at least expedient, to purify the ore as such before the liberation of the metal is attempted. Most metallic ores are specifically heavier than the impurities accompanying them, and their purification may be (and generally is) effected by reducing the crude ore to a fine enough powder to detach the metallic from the earthy part, and then washing away the latter by a current of water, as far as possible. In the case of a "reguline" ore, such as auriferous quartz, for instance, the ore thus concentrated may consist substantially of the metal itself, and require only to be melted down and cast into ingots to be ready for the market. This, however, is a rare case, the vast majority of ores being chemical compounds, which for the extraction of their metals demand chemical treatment. The chemical operations involved may be classified as follows:—

1. **Fiery Operations.**—The ore, along in general with some kind of "flux," is exposed to the direct action of a powerful fire. The fire in most cases has a chemical, in addition to its obvious physical function. It is intended either to burn away certain components of the ore—in which case it must be so regulated as to contain a sufficient

excess of unburned oxygen; or it is meant to deoxidize ("reduce") the ore, when the draught must be restricted so as to keep the ore constantly wrapped up in combustible flame gases (carbonic oxide, hydrogen, marsh-gas, &c.). The vast majority of the chemical operations of metallurgy fall into this category, and in these processes other metal-reducing agents than those naturally contained in the fire (or wind) are only exceptionally employed.

2. **Amalgamation.**—The ore by itself (if it happens to be a reguline one), or the ore plus certain reagents (if it does not), is worked up with mercury so that the metal is obtained ultimately as an amalgam, which can be separated mechanically from the dross. The purified amalgam is subjected to distillation, when the mercury is recovered as a distillate while the metal remains.

3. **Wet Processes.**—Strictly speaking, certain amalgamation methods fall under this head; but, in its ordinary acceptance, the term refers to processes in which the metal is extracted either from the natural ore, or from the ore as it is after roasting or some other preliminary treatment, by means of an aqueous acid or salt solution, and from this solution precipitated—generally in the reguline form—by some suitable reagent.

Few methods of metal extraction at once yield a pure product. What as a rule is obtained is a more or less impure metal, which requires to be "refined" to become fit for the market. We now pass to the individual consideration of the several steps referred to.

**Comminution of Ores.**—Assuming the ore to be given in the shape of large lumps, these must first be broken up into small stones (of about the size of those used for macadamizing a road) before they can go to the grinding-mill. This formerly used to be done by hand-work; nowadays it is preferably effected by means of an American invention called the stone-breaker (fig. 1). This consists essentially of two substantial vertical iron plates; one is fixed, the other is connected with an eccentric worked by an engine so as to alternately dash against and recede from the former. The lumps of ore, in passing through this jaw-like contrivance are broken up into smaller fragments fit for

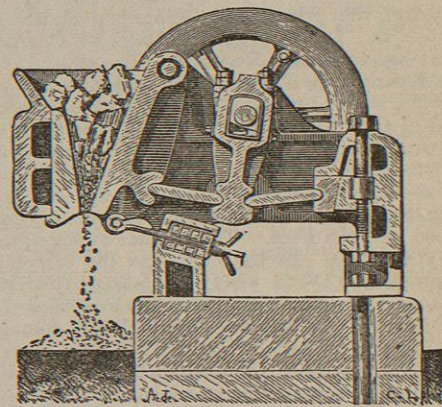


FIG. 1.—American Stone-Breaker.

the mill. For the production of a coarse powder revolving cylinders are often employed. Two cylinders of equal diameter and length, made of iron, steel, or stone, are suspended by parallel axes in close proximity to each other. The width of the slit between them can be made to vary according to the requirements of the case. The cylinders are made to revolve in opposite directions, so that the stones when run into the groove formed by their upper halves are drawn between them and are crushed into bits of a size depending on the least distance between the two surfaces. Exceptionally hard stones might bring the machine to a standstill or cause breakages; hence only one of the two axes of rotation is absolutely fixed; the cushions of the other are only held in relatively fixed positions, each between a couple of guiding rails, by means of powerful springs at their backs. The springs are made of alternate disks of india-rubber and sheet-iron, and yield appreciably only to very strong pressures. When an exceptionally hard stone comes on, they yield

and allow it to pass through uncrushed. Sometimes two sets of cylinders are arranged one above the other, so that the grit from the upper falls into the jaws of the lower set to receive further comminution. The diameter of the cylinders is from a foot to a yard, their length from 9 inches to a yard, the velocity of a point on the periphery a foot to a yard per second. The quantity of ore reduced per hour per horse-power is about 5 cubic feet for quartz or other hard minerals, and about 14 cubic feet for minerals of moderate hardness.

For the production of a relatively fine powder the pounding-mill is frequently used, which, in its action, is analogous to a mortar and pestle. The mortar is a rectangular trough, while the pestle is replaced by a parallel set of heavy metal or metal-shod beams, which (by means of a revolving cylinder with cogs catching projections on the beams) are lifted up in succession and then let fall by their own weight so as to pound up the ore in the trough. The ore is supplied from a prismatic reservoir with a sloping bottom leading into a canal through which the stones slide into the trough. A current of water, which constantly flows into the trough from below, lifts up the finer particles and carries them away over the edge of the trough into a settling tank.

The object pursued in powdering an ore is to prepare it for being purified by washing. But the velocity with which a solid particle falls through water depends on its size as well as on its specific gravity—an increase in either accelerating the fall; hence, where the difference in specific gravity between the things to be separated is small, the washing must be preceded by a separation of the ore-powder into portions of approximately equal fineness. This is often effected by passing the ore through a system of sieves of different width of mesh superposed over one another, the coarser sieve always occupying the higher position. Sometimes the sieves are made to "go dry," sometimes they are aided in their action by a current of water which, more effectually than mere shaking, prevents adherence of dust to coarser parts.

Another contrivance is the "Drum" (fig. 2). A long perforated circular cylinder made of sheet-iron, open at both ends, is suspended, in a sloping position, by a revolving shaft passing through its axis. The size of the perforations is generally made to increase in passing from the upper to the lower belts of the cylinder. While the drum

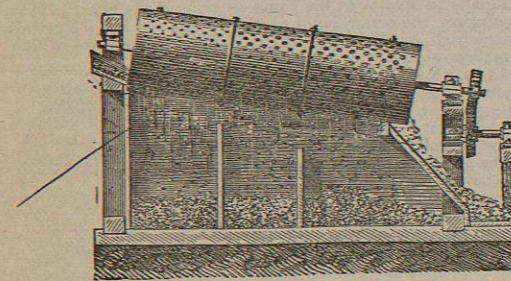


FIG. 2.—Drum.

is revolving, the ore, suspended in water, flows in at the upper end, and in travelling down it casts off first its finest and then its coarser parts, the coarsest only reaching the exit at the lower end. The several grades of powder produced fall each into a separate division of the collecting tank.

The drum, of course, is subject to endless modifications. A very ingenious combination is H. E. Taylor's "Drum Dressing Machine" (fig. 3). It consists of three truncated cone-shaped drums D, fixed co-axially to the same horizontal revolving shaft,

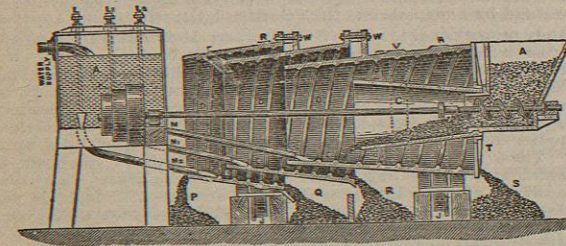


FIG. 3.—Taylor's Drum Dressing Machine.

so that the narrow end of No. 1 projects into the wider end of No. 2, and No. 2 similarly into No. 3. The drums are not perforated, but are armed inside with screw-threads formed of strips of sheet metal

fixed edgewise to the drum. The ore grit to be dressed is placed in a hopper A, and from it, by a worm B fixed to the revolving shaft, is being screwed forward into a short fixed truncated cone C projecting into the revolving drum No. 1, into which it flows in a constant current. The rotary motion of the drum tends to convey the ore along the spiral path prescribed by the screw-thread towards the other end, and from it into drum No. 2, and so on. But the ore in each drum meets with a jet of water E impelling it the opposite way, and the effect is that, in each drum, the lighter parts follow the water, and with it run off over the entrance edge to be collected in a special tank, while the coarser parts roll down the spiral path toward the next drum to undergo further parting. The tank or pit for drum 1 receives the finest and lightest parts, that of drum 2 a heavier, that of drum 3 a still heavier portion, while only the very heaviest matter finds its way out of the exit end of No. 3 into a fourth receptacle.

Of the large number of other ore-dressers, only two need be mentioned here.

The "Clausen Turn-Table" consists of a circular table, the surface of which rises from the periphery towards the centre so as to form a very flat cone of about 170°, which is fixed co-axially to a vertical rotary shaft. At the apex of the table, surrounding the shaft, but independent of its motion, there is a circular trough of sheet zinc, divided into two compartments; one receives a stream of water carrying the ore, the other a supply of pure water. A large annular trough of sheet zinc is placed below the periphery of the table, so as to receive whatever may fall over the edge. It also is divided into compartments, as shall be explained further on. Supposing the table to be at rest, a sector of about 60° of it would be constantly run over by the ore-mud out of the first compartment of the upper trough. This mud current would suffer partial separation into heavier and lighter parts,—rich ore resting in the higher and poorer in the lower latitudes, and a still poorer ore falling over the periphery into the lower trough. The same happens with the moving table; only each sector of such partially analysed ore undergoes further purification by passing through about 90° of water-shower. After passing this, it meets with a perforated fixed water-pipe going up radially to about half the radius of the table. This pipe also carries sweeping brushes, so that the belt of ore from the lower latitudes of the table is swept off into the corresponding section of the receiving trough. What of ore remains on the higher latitudes subsequently meets with a similar arrangement which sweeps it off into its compartment. If the table turns from the left to the right, and we follow the process, beginning at the left edge of the ore-mud compartment, it will be seen that a first sector of the receiving trough gathers the light dross, a succeeding one an intermediate product, a third the most highly purified ore. The "intermediate" is generally run into the ore-mud trough of a second table to be further analysed.

In the "Continuous Wash-Pumps" (Continuirliche Setzpumpe) of the Harz, three funnel-shaped vessels (one of which is shown in fig. 4) are set in a frame beside one another, but at different levels, so that any overflow from No. 1 runs into No. 2 and thence into No. 3. Each funnel communicates below with its own compartment of a common cistern.

Into each funnel a riddle with narrow meshes is inserted somewhere near the upper end, while, beside the riddle, there is a pump of short range, which, by means of an eccentric, is worked so that the piston alternately goes rapidly down and slowly up. The mode of working is best explained by an example. At Breinigerberg in Rhenish Prussia the apparatus serves to separate a complex ore into the following four parts, which we enumerate in the order of their specific gravities—(1) galena (the heaviest), (2) pyrites, (3) blende, (4) dross. Sieve No. 1 is charged with granules of galena, just large enough not to slip through the meshes, No. 2 similarly with granules of pyrites, No. 3 with those of blende. The crude ore-mud goes into sieve 1; the jerking action of the pump alternately tosses the particles up into the water and allows them to fall; the heaviest naturally come down first, but what is most striking is that nothing will pass through the bed of galena but what is at least as heavy as galena itself. In a similar manner No. 2 and No. 3

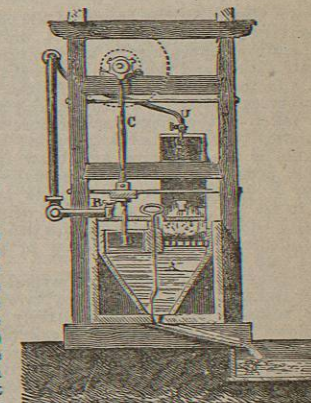


FIG. 4.—Continuous Wash-Pump.

funnels sift out the pyrites and the blende respectively, so that almost nothing but dross runs off ultimately. The apparatus is said to do its work with a wonderful degree of precision, and of course is susceptible of wider application, but it ceases to work when the raw material is a slime so fine that the particles fall too slowly.

**Modes of Producing High Temperatures.**—Most of what is to be said on this topic has already been anticipated in the articles FUEL, FURNACE, and BELLOWS; but a few notes may be added on specially metallurgic points.

**Furnace Materials.**—In a metallurgic furnace the working parts at least must be made of special materials capable of withstanding the very high temperatures to which they are exposed and the action of the fluxes which may be used. No practically available material fully meets both requirements, but there is no lack of merely fire-proof substances.

Of native stones, a pure quartzose sandstone, free from marl, may be named as being well adapted for the generality of structures; but such sandstone, or indeed any kind of fire-proof stone, is not always at hand. What is more readily procured, and consequently more widely used, is refractory brick, made from "fire-clay." The characteristic chemical feature of fire-clays is that in them the clay proper (always some kind of hydrated silicate of alumina) is associated with only small proportions of lime, magnesia, ferrous oxide, or other protoxides. If the percentage of these goes beyond certain limits, the bricks, when strongly heated, melt down into a slag. The presence of free silica, on the other hand, adds to their refractoriness. In fact the best fire-bricks in existence are the so-called Dinas bricks, which consist substantially of silica, contaminated only with just enough of bases to cause it to frit together on being baked. Dinas bricks, however, on account of their high price, are reserved for special cases involving exceptionally high temperatures. Amongst ordinary fire-bricks those from Stourbridge enjoy the highest reputation. It follows from what has just been said that, in a metallurgic furnace, lime-mortar cannot be used as a cement, but must be replaced by fire-clay paste.

In the construction of cupels, reverberatory furnaces, &c., only the general groundwork is, as a rule, made of built bricks, and this groundwork is coated over with some kind of special fire-proof and flux-proof material, such as bone-ash, a mixture of baked fire-clay and cokes or graphite, or of quartz and very highly silicated slags, &c. These beddings are put on in a loose powdery form, and then stamped fast. They offer the advantage that, when worn out, they are easily removed and renewed. The powerful draught which a metallurgic fire needs can be produced by a chimney, where the fuel forms a relatively shallow layer spread over a large grating; but, when closely-packed deep masses of fuel or fuel and ore have to be kept ablaze, a blast becomes indispensable.

**Chimneys.**—The efficiency of a chimney is measured by the velocity  $V$  with which the air ascends through it, multiplied by its section; and the former is in roughly approximate accordance with the formula

$$V = k \sqrt{2gh(T - T_0)/T_0}$$

where  $h$  stands for the height of the chimney,  $g$  for the acceleration of gravity (32.2 feet per second), and  $T$  and  $T_0$  for the absolute temperatures (meaning the temperatures counted from  $-273^\circ \text{C.}$ ) of the air within and the air without the chimney respectively, while  $k$  is a factor meant to account for the resistances which the air, in its progress through the furnace, &c., has to overcome. In practice  $T$  is taken as the mean temperature of the chimney gases, which theoretically is not unobjectionable; but the weakest point in the formula is the smallness and utter inconstancy of the factor  $k$ , which, according to Péclet, generally assumes some value of the power  $\frac{1}{2}$ ,  $\frac{1}{3}$ , &c. Yet the formula is of some use as enabling one to see the way in which  $V$  depends on  $h$  and  $(T - T_0)/T_0$  conjointly,—to see, for instance, how deficient chimney height may be compensated for by an increase of temperature in the chimney gases, and vice versa.

**Blowing-Machines.**—Of the several kinds of blowers described under BELLOWS (*q.v.*), the "fans" are the best means for producing large volumes of wind of relatively small but steady pressure; "bellows" are indicated in the case of work on a relatively small scale requiring moderate wind pressure; while the "cylinder blast" comes in where large masses of high-pressure wind are required. Two highly interesting blowing-machines, however, are omitted in that article, which may be shortly described here.

The "Water Blast" (Wassertrommelgeblase) is interesting historically, having been used metallurgically in Hungary for many centuries. A mass of water, stored up in a reservoir, is made to fall down continuously through a high narrow vertical shaft having air-holes at its upper end. The vortical column of water sucks in air through these holes and carries it down with it into a kind of inverted tub standing in a reservoir kept at a constant level. Air and water there separate, the former flowing away through a pipe into a wind-box, from which it is led to its destination.

The "Cagniardelle" (figs. 5, 6), so called from its inventor Cagniard Latour, also utilizes water to carry air, but in quite another way. By means of a round shaft passing through its axis, a cylindrical drum of sheet-metal is suspended slantingly in a mass of water, so that the lower end is fully immersed, while of the upper end the segment above the upper side of the shaft is uncovered. The space between shaft and drum is converted into a very wide screw-shaped canal by a band of sheet-metal hermetically fixed edgewise to the two. Both the top and the bottom end of the drum are partially closed by flat

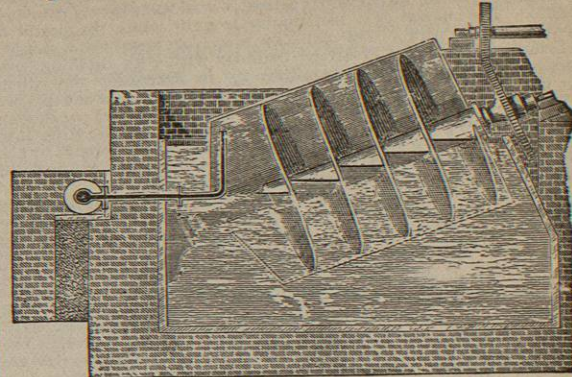


Fig. 5.—Cagniardelle.

bottoms soldered or riveted to the respective edges; the lower one leaves a ring-shaped opening between its edge and the shaft, which serves for the introduction of a fixed air-pipe bent so as to reach up to near the top of the drum's air-space; in the upper bottom three quadrants are closed, the fourth is open. Supposing the screw-canal, traced from below, to go from the left to the right, the drum is made to revolve in the same sense, and the effect is that, in each revolution, the screw-canal at its top end swallows a certain volume of air which, by the succeeding entrance of the water—which

of course, moves relatively to the screw—is pushed towards and ultimately into the air-space at the bottom end. The Cagniardelle yields a perfectly continuous blast, and, as it is not encumbered with any dead resistances except the friction of the shaft against its bearings (which can be reduced to very little) and the very slight friction of the water against the screw-canal, it utilizes a very large percentage of the energy spent on it. This percentage, according to experiments by Schwamkrug, amounts to from 75 to 84.5; in the case of the cylinder-blast it is 60 to 65 per cent., with bellows, about 40 per cent.; with the "Wassertrommelgeblase" 10 to 15 per cent. Hence the "Wassertrommelgeblase" stands last in relative efficiency; but we must not forget that it alone directly utilizes native energy, while, in the cylinder blast, for example, 100 units of work done by the steam-engine involve a vastly greater energy spent on the engine as heat.

To maintain a desired temperature in a given furnace charged in a certain manner, the introduction of a certain volume of air per unit of time is necessary. But this quantity, in a given blowing-machine, is determined by the over-pressure of the wind, as measured by a manometer, the velocity of the wind being approximately proportional to  $\sqrt{M/(B+M)}$ , where  $M$  stands for the height of the mercury-manometer, and  $B$  for that of the barometer. Hence the practical metallurgist, in adjusting his blast, has nothing to do but to see that the manometer shows the reading which, by previous trials, has been proved to yield an adequate supply of wind.

**Fuel.**—In some isolated cases the ore itself, by its combustion, supplies the necessary heat for the operation to be performed upon it. Thus, for instance, the roasting of blackband iron-stone is effected by simply piling up the ore and setting fire to it, so that the ore is at the same time its own furnace and fuel; in the Bessemer process of steel-making, the burning carbon of the pig-iron supplies the heat necessary for its own combustion; and a similar process has been tried experimentally, and not without success, for the working up of certain kinds of pyrites. But, as a rule, the high temperatures required for the working of ores are produced by the combustion of extraneous fuel, such as wood, wood-charcoal, coal, coke. Of these four, wood-charcoal is of the widest applicability, but not much used in Britain on account of its high price. High-class coke or pure anthracite, volume for volume,

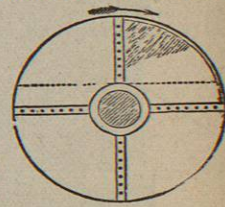


Fig. 6.

gives the highest temperature. Wood or coal is indicated when a voluminous flame is one of the requisites. Obviously fuel of the same kind and quality gives a higher calorific intensity when, before use, it is deprived by drying of its moisture, or when it is used in conjunction with a hot instead of a cold blast. This latter principle, as every one knows, is largely discounted in the manufacture of pig-iron, where nowadays coal, with the help of the hot blast, is made to do what formerly could only be effected with charcoal or coke. For further information see FUEL and IRON.

**Chemical Operations.**—In regard to processes of amalgamation and to wet-way processes, we have nothing to add to what was given in a previous paragraph; we therefore here confine ourselves, in the main, to pyro-chemical operations.

The method to be adapted for the extraction of a metal from its ore is determined chiefly, though not entirely, by the nature of the non-metallic component with which the metal is combined. The simplest case is that of the reguline ores where there is no non-metallic element. The important cases are those of GOLD, BISMUTH, and MERCURY (*q.v.*).

**Oxides, Hydrates, Carbonates and Silicates.**—All iron and tin ores proper fall under this heading, which, besides, comprises certain ores of copper, of lead, and of zinc. In any case the first step consists in subjecting the crude ore to a roasting process, the object of which is to remove the water and carbonic acid, and burn away, to some extent at least, what there may be of sulphur, arsenic, or organic matter. The residue consists of an impure (perhaps a very impure) oxide of the respective metal, which in all cases is reduced by treatment with fuel at a high temperature. Should the metal be present in the silicate form, lime must be added in the smelting to remove the silica and liberate the oxide.

In the case of zinc the temperature required for the reduction lies above the boiling point of the metal; hence the mixture of ore and reducing agent (charcoal is generally used) must be heated in a retort combined with the necessary condensing apparatus. In all the other cases the reduction is effected in the fire itself, a tower-shaped blast furnace being preferably used. The furnace is charged with alternate layers of fuel and ore (or rather ore and flux, see below), and the whole kindled from below. The metallic oxide, partly by the direct action of the carbon with which it is in contact, but principally by that of the carbonic oxide produced in the lower strata from the oxygen of the blast and the hot carbon there, is reduced to the metallic state; the metal fuses and runs down, with the slag, to the bottom of the furnace, whence both are withdrawn by the periodic opening of plug-holes provided for the purpose.

**Sulphides.**—Iron, copper, lead, zinc, mercury, silver, and antimony very frequently present themselves in this state of combination, as components of a very numerous family of ores which may be divided into two sections: (1) such as substantially consist of simple sulphides, as iron pyrites ( $\text{FeS}_2$ ), galena ( $\text{PbS}$ ), zinc blende ( $\text{ZnS}$ ), cinnabar ( $\text{HgS}$ ); and (2) complex sulphides, such as the various kinds of sulphureous copper ores (all substantially compounds or mixtures of sulphides of copper and iron); bournonite, a complex sulphide of lead, antimony, and copper; rothgiltigerz, sulphide of silver, antimony, and arsenic; fallerz, sulphides of arsenic and antimony, combined with sulphides of copper, silver, iron, zinc, mercury, silver; and mixtures of these and other sulphides with one another.

In the treatment of a sulphureous ore, the first step as a rule is to subject it to oxidation by roasting it in a reverberatory or other furnace, which, in the first instance, leads to the burning away of at least part of the arsenic and part of the sulphur. The effect on the several individual metallic sulphides (supposing only one of these to be present) is as follows:—

1. Those of silver ( $\text{Ag}_2\text{S}$ ) and mercury ( $\text{HgS}$ ) yield sulphurous acid gas and metal; in the case of silver, sulphate is formed as an intermediate product, at low temperatures. Metallic mercury, in the circumstances, goes off as a vapour, which is collected and condensed; silver remains as a regulus, but pure sulphide of silver is hardly ever worked.

2. Sulphides of iron and zinc yield the oxides  $\text{Fe}_2\text{O}_3$  and  $\text{ZnO}$  as final products, some basic sulphate being formed at the earlier stages, more especially in the case of zinc. The oxides can be reduced by carbon.

3. The sulphides of lead and copper yield, the former a mixture of oxide and normal sulphate, the latter one of oxide and basic sulphate. Sulphate of lead is stable at a red heat; sulphate of copper breaks up into oxide, sulphurous acid, and oxygen. In practice, neither oxidation process is ever pushed to the end; it is stopped as soon as the mixture of roasting-product and unchanged sulphide contains oxygen and sulphur in the ratio of  $\text{O}_2:\text{S}$ . The access of air is then stopped and the whole heated to a higher temperature, when the potential  $\text{SO}_2$  actually goes off as sulphurous acid gas and the whole of the metal is eliminated as such. This method is largely utilized in the smelting of lead (from galena) and of copper from copper pyrites. In the latter case, however, the

<sup>1</sup> Examples are given in GOLD and COPPER. See also SILVER.

sulphide  $\text{Cu}_2\text{S}$  has first to be produced from the ore, which is done substantially as follows. The ore is roasted with silica until a certain proportion of the sulphur is burned away as  $\text{SO}_2$ , while a corresponding proportion of oxygen has gone to the metal part of the ore. Now it so happens that copper has a far greater affinity for sulphur than iron has; hence any locally produced oxide of copper, as long as sufficient sulphide of iron is left, is sure to be reconverted into sulphide, and the final result is that, while a large quantity of oxidized iron passes into the slag, all the copper and part of the iron separate out as a mixed regulus of  $\text{Cu}_2\text{S}$  and  $\text{FeS}$  ("mat"). This regulus, by being fused up repeatedly with oxidized copper ores or rich copper slags (virtually with  $\text{CuO}$  and silica), gradually yields up the whole of its iron, so that ultimately a regulus of pure sub-sulphide of copper,  $\text{Cu}_2\text{S}$  ("fine mat"), is obtained, which is worked up for metal as above explained.

4. Sulphide of antimony, when roasted in air, is converted into a kind of alloy of sulphide and oxide; the same holds for iron, only its oxysulphide is quite readily converted into the pure oxide  $\text{Fe}_2\text{O}_3$  by further roasting. Oxysulphide of antimony, by suitable processes, can be reduced to metal, but these processes are rarely used, because the same end is far more easily obtained by "precipitation," i.e., withdrawing the sulphur by fusion with metallic iron, forming metallic antimony and sulphide of iron. Both products fuse, but readily part, because fused antimony is far heavier than fused sulphide of iron is. A precisely similar method is used occasionally for the reduction of lead from galena. Sulphide of lead when fused together with metallic iron in the proportion of  $2\text{Fe} : 1\text{PbS}$  yields a regulus ( $-1\text{Pb}$ ) and a "mat"  $\text{FeS}$ , which, however, on cooling, decomposes into  $\text{FeS}$  parts of ordinary sulphide and  $\text{Fe}$  parts of finely divided iron. What we have just been explaining are only two special cases of a more general metallurgic proposition. According to Fournet, any one of the metals copper, iron, tin, zinc, lead, silver, antimony, arsenic, in general, is capable of desulphurizing or precipitating (at least partially) any of the others that follows it in the series just given, and it does so the more readily and completely the greater the number of intervening terms. Hence, supposing a complete mixture of these metals to be melted down under circumstances admitting of only a partial sulphuration of the whole, the copper has the best chance of passing into the "mat," while the arsenic is the first to be eliminated as such, or, in the presence of oxidants, as oxide.

**Arsenides.**—Although arsenides are amongst the commonest impurities of ores generally, ores consisting essentially of arsenides are comparatively rare. The most important of them are certain double arsenides of cobalt and nickel, which in practice, however, are always contaminated with the arsenides or other compounds of foreign metals, such as iron, manganese, &c. The general mode of working these ores is as follows. The ore is first roasted by itself, when a part of the arsenic goes off as such and as oxide (both volatile), while a complex of lower arsenides remains. This residue is now subjected to careful oxidizing fusion in the presence of glass or some other fusible solvent for metallic bases. The effect is that the several metals are oxidized away and pass into the slag (as silicates) in the following order,—first the manganese, secondly the iron, thirdly the cobalt, lastly (and very slowly) the nickel; and at any stage the as yet unoxidized residue of arsenide assumes the form of a fused regulus, which sinks down through the slag as a "speis." (This term, as will readily be understood, has the same meaning in reference to arsenides as "mat" has in regard to sulphides.) By stopping the process at the right moment, we can produce a speis which contains only cobalt and nickel, and if at this stage also the flux is renewed we can further produce a speis which contains only nickel and a slag which substantially is one of cobalt only. The composition of the speises generally varies from  $\text{AsMe}_{2/3}$  to  $\text{AsMe}$ , where "Me" means one atomic weight of metal in toto, so that in general  $1\text{Me} = x\text{Fe} + y\text{Co} + z\text{Ni}$ , where  $x + y + z = 1$ . The siliceous cobalt is utilized as a blue pigment called "smalte"; the nickel-speis is worked up for metal, preferably by wet processes.

**Minor Reagents.**—Besides the oxidizing and reducing agents naturally present in the fire, and the "fluxes" added for the production of slags, there are various minor reagents, of which the more important may be noticed here. One—namely, metallic iron as a desulphurizer—has already been referred to.

Oxide of lead,  $\text{PbO}$  (litharge), is largely used as an oxidizing agent. At a red heat, when it melts, it readily attacks all metals, except silver and gold, the general result being the formation of a mixed oxide and of a mixed regulus, a distribution, in other words, of both the lead and the metal acted on between slag and regulus. More important and more largely utilized is its action on metallic sulphides, which, in general, results in the formation of three things besides sulphurous acid gas, viz., a mixed oxide slag including the excess of litharge, a regulus of lead (which may include bismuth and other more readily reducible metals), and, if the litharge is not sufficient for a complete oxidation, a "mat" comprising the more readily sulphurizable metals. Oxide of lead, being a most powerful solvent for metallic oxides generally, is also

largely used for the separation of silver or gold from base metallic oxides.

Metallic lead is to metals generally what oxide of lead is to metallic oxides. It accordingly is available as a solvent for so to say licking up small particles of metal diffused throughout a mass of slag or other dross, and uniting them into one regulus. This naturally leads us to consider the process of "cupellation," which discounts the solvent powers of both metallic lead and its oxide. This process serves for the extraction of gold and silver from their alloys with base metals such as copper, antimony, &c. The first step is to fuse up the alloy with a certain proportion of lead, which is determined by the weight of base metal to be eliminated, and is always sufficient to produce a lead-alloy of low fusing point. This alloy is heated on a shallow dish-shaped bed of bone earth to redness, and at this temperature subjected to the action of air. The base metals (copper, &c.) are oxidized away, the first portions as an infusible scum containing little oxide of lead, the latter in the form of a solution in molten litharge. Lead is, in general, less oxidizable than the other base metals; hence the last instalment of liquid litharge which runs off is pure, and the ultimately remaining regulus consists of silver and gold only. These latter may be separated by nitric acid or boiling oil of vitriol, which converts the silver into soluble salts and leaves the gold.

Oxide of iron, and also binoxide of manganese, are used for the decarburization of pig-iron. The oxygen of the reagent burns the carbon of the pig into carbonic acid, while the metal of the reagent becomes iron and FeO or MnO respectively, the oxides uniting with the silica added as such, or formed by the oxidation of the silicon of the pig, into a fusible slag.

Iron pyrites, FeS<sub>2</sub>, is employed for the preliminary concentration of traces of gold diffused throughout slags or base ores. The reagent, through the action of the heat, gives up one-half of its sulphur, which reduces part of the metallic oxides present. The gold and silver unite with what is left of protosulphide of iron (FeS) into a mat, which is then worked up for the noble metals.

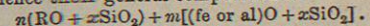
**Fluxes.**—Practically speaking, all ores are contaminated with more or less of gangue, which in general consists of infusible matter, and consequently, if left unheeded in the reduction of the metallic part of the ore, would retain more or less of the metal disseminated through it, or at best foul the furnace. To avoid this, the ore as it goes into the furnace is mixed with "fluxes" so selected as to convert the gangue into a fusible "slag," which readily runs down through the fuel with the regulus and separates from the latter. The quality and proportion of flux should, if possible, be so chosen that the formation of the slag sets in only after the metal has been reduced and molten; or else part of the basic oxide of the metal to be extracted may be dissolved by the slag and its reduction thus be prevented or retarded. Slags are not, as one might be inclined to think, a necessary evil; if an ore were free from gangue we should add gangue and flux from without to produce a slag, because one of its functions is to form a layer on the regulus which protects it against the further action of the blast or furnace gases. Fluxes may be arranged under the three heads of (1) fluor-spar (which is *sui generis*), (2) basic fluxes, and (3) acid fluxes.

Fluor-spar owes its name to the facility with which it fuses up at a red heat with silica, sulphates of lime and barium, and a few other infusible substances into homogeneous masses. It shows little tendency to dissolve basic oxides, such as lime, &c. One part of fluor-spar liquefies about half a part of silica, four parts of sulphate of lime, and one and a half parts of sulphate of baryta. Upon these facts its wide application in metallurgy is founded.

Carbonate of soda (or potash) may be said to be the most powerful of basic fluxes. It dissolves silica and all silicates into fusible masses. On the other hand, borax may be taken as a type for the acid fluxes. At a red heat, when it forms a viscid fluid, it readily dissolves up all basic oxides into fusible complex borates. Now the gangue of an ore in general consists either of some basic material such as carbonate of lime (or magnesia), ferric oxide, alumina, &c., or of silica (quartz) or some more or less acid silicate, or else of a mixture of the two classes of bodies. So any kind of gangue might be liquefied by means of borax or by means of alkaline carbonate; but neither of the two is used otherwise than for assaying; what the practical metal-smelter does is to add to a basic gangue the proportion of silica, and to an acid ore the proportion of lime, or, indirectly, of ferrous or perhaps manganous oxide, which it may need for the formation of a slag of the proper qualities. The slag must possess the proper degree of saturation. In other words, taking SiO<sub>2</sub> + nMeO (where MeO means an equivalent of base) as a formula for the potential slag, n must have the proper value. If n is too small, i.e., if the slag is too acid, it may dissolve up part of the metal to be brought out as a silicate; if n is too great, i.e., the slag too basic, it may refuse to dissolve, for instance, the ferrous oxide which is meant to go into it, and this oxide will then be reduced, and its metal (iron in our example) contaminate the regulus. In reference to the problem under discussion, it is worth noting that oxides of lead and copper are more readily reduced to metals than oxide of iron Fe<sub>2</sub>O<sub>3</sub> is to FeO, the latter more readily to FeO than

FeO itself to metal, and FeO more readily to metal than manganous oxide is. Oxide of calcium (lime) is not reducible at all. The order of basicity in the oxides (their readiness to go into the slag) is precisely the reverse.

Most slags being, as we have seen, complex silicates, it is a most important problem of scientific metallurgy to determine the relations in this class of bodies between chemical composition on the one hand and fusibility and solvent power for certain oxides (CaO, FeO, SiO, &c.) on the other. Now the composition of a silicate can be stated in an infinite number of ways; but there must be one mode of formulation which reduces the law to its simplest terms. The mode adapted by metallurgists is something like the following. If we start with the quantity H<sub>2</sub>O, of muriatic acid or the quantity H<sub>2</sub>SO<sub>4</sub> of sulphuric acid, it is clear that to convert either into a normal salt we require such a quantity of base as will convert the H<sub>2</sub> of the acid completely into water; but the quantity of base that does so is that containing one atomic weight of oxygen. Hence it is reasonable to define the quantities K<sub>2</sub>O of potash, Na<sub>2</sub>O of soda, CaO of lime, MgO of magnesia, FeO of ferrous oxide,  $\frac{1}{2}$ Al<sub>2</sub>O<sub>3</sub> (=alO) of alumina,  $\frac{1}{2}$ Fe<sub>2</sub>O<sub>3</sub> (=FeO) of ferric oxide, as representing each "one equivalent" of base also in reference to silica, although silica has a characteristically indefinite basicity. Most slags are alloys or compounds of silicates of Al<sub>2</sub>O<sub>3</sub> or Fe<sub>2</sub>O<sub>3</sub>, and of silicates of protoxides (CaO, &c.), hence their general composition is



This introduction will enable the reader to understand the following mode of classifying and naming composition in silicates.

Name.	Formula.	Oxygen Ratio.		x
		Base.	Acid.	
I. Singulo-silicates.....	SiO <sub>2</sub> +1MO	1	1	$\frac{1}{2}$
II. Bi-silicates.....	SiO <sub>2</sub> +1MO	1	2	$\frac{1}{3}$
III. Tri-silicates.....	SiO <sub>2</sub> +1MO	1	3	$\frac{1}{4}$

The names are the metallurgic ones; scientific chemists designate Class I. as orthosilicates, Class II. as metasilicates, Class III. as sesquosilicates. In the formulae M stands for K, Ca, Fe, &c., or for al- $\frac{1}{2}$ Al, Fe- $\frac{1}{2}$ Fe, &c.; or, shortly, MO for one equivalent of base as above defined. It should be possible to represent each quality of a silicate as a function of  $\frac{x}{m}$ , and of the nature of the individual bases that make up the RO and (fe or al) O respectively. Our actual knowledge falls far short of this possibility. The problem, in fact, is a very tough one, the more so as it is complicated by the existence of aluminates, compounds such as Al<sub>2</sub>O<sub>3</sub>.3CaO, in which the alumina plays the part of acid, and the occasional existence of compounds of fluorides and silicates in certain slags. The following notes on the fusibility of simple silicates are taken from Plattner's researches. Of the lime silicates, the tri-silicate melts at 2100° C., the bi-silicate at 2150°.

Magnesia silicates are most refractory. The bi-silicate and tri-silicate melt in the oxyhydrogen flame at 2250°.

Of manganous silicates, the easily fusible bi-silicate is yellow or red; the tri-silicate is more refractory.

Of cuprous (Cu<sub>2</sub>O) silicates, the bi-silicate is violet, and melts pretty easily; the singulo-silicate is red, dense, and rather refractory.

Cupric silicates, as slags, hardly exist,—the CuO being always reduced to at least Cu<sub>2</sub>O.

Lead silicates all melt readily into yellowish transparent glasses. But they have no standing as slags.

As regards the ferrous silicates, the singulo-silicate (orthosilicate) fuses at 1790° (this is about the composition of iron-puddling slag); the bi-silicate is less readily fusible.

Ferric silicates (unmixed) do not exist as slags,—the Fe<sub>2</sub>O<sub>3</sub> being reduced in the fire to 1FeO, although Fe<sub>2</sub>O<sub>3</sub> occasionally replaces part of the Al<sub>2</sub>O<sub>3</sub> in complex silicates.

Alumina silicates are all infusible in even the hottest furnace fires. They begin to soften in the oxyhydrogen flame at about 2400°. But certain aluminates, for instance the salt 3CaO.1Al<sub>2</sub>O<sub>3</sub>, according to Sefström, melt at furnace heats.

The fusing points of mixtures of two simple silicates cannot be calculated from those of the components. In many cases it is lower than either of the latter two. Thus for instance most magnesia-lime silicates fuse,—the bi-silicate combination (Mg, Ca)OSiO<sub>2</sub> most readily.

Alumina silicates become fusible by addition of a sufficient proportion of silicate of lime at about 1918°. The singulo-silicate and bi-silicate combinations melt into grey glasses. Magnesia acts like lime, and so, in a more limited sense, do ferrous and manganous oxides; but their double compounds with Al<sub>2</sub>O<sub>3</sub> and silica are more viscid when fused.

Plattner's work is a bold attempt to deal synthetically with the problem here presented, but it does not go the length of even an approximate solution. No one seems to have done much to continue it; hence in the meantime the metallurgist has, for his

<sup>1</sup> Few slags contain more than traces of alkalies.

guidance, to rely on the very numerous analyses which have been made of slags actually produced (by the rule of thumb) in successful metallurgical operations. For some of such slags also Plattner has determined the fusing points. He found for (1) Freiberg lead slag, 9RO, 3alO, 8SiO<sub>2</sub>; oxygen-ratio, 3:4; melting-point at 1317° C.; (2) Freiberg crude slag, 15RO, 3alO, 18SiO<sub>2</sub>; oxygen-ratio, 1:1; melting-point at 1331° C.; (3) Freiberg black-copper slag, 24FeO, Al<sub>2</sub>O<sub>3</sub>, 15SiO<sub>2</sub>; oxygen-ratio, 9:10; melting-point at 1338° C.; (4) High-furnace slag, 6CaO, 3alO, 9SiO<sub>2</sub>; oxygen-ratio, 1:1; melting-point at 1431° C.<sup>1</sup>

**Metallurgic Assaying.**—To assay an ore originally meant to execute a set of tentative experiments on a small scale in order to find out the proper mode of working it practically. But nowadays the term is always used in the sense of an analysis carried out to determine the money-value of an ore. For this purpose, in many cases it is sufficient to determine the percentages of the metals for which the ore is meant to be worked. But sometimes nothing short of a complete analysis will do. This holds more especially of ores of iron. As this metal is cheap, the value of an ore containing it depends as much on the nature and relative quantities of the impurities as on the percentage of metal. The proved absence of sulphur and phosphorus may be worth more than an additional 5 per cent. of iron, which latter again would perhaps not compensate for the proved presence of a large percentage of uncombined silica.

An assay to be of any value must start with a fair sample of the object of sale. The fulfilment of this condition in all cases is difficult. The general method is, from say a given ship load of ore, to take out (say) half a ton of ore from a large number of different places and to crush this large sample into small fragments of uniform size, which are well shovelled up together. From different parts of this ore-heap a sample of the second order—amounting to, say, 20 lb—is then drawn, and rendered more homogeneous by finer powdering and mixing. From this sample of the second (or perhaps from one of the third) order quantities of 1 or 2 lb are bottled up for assaying. At the same time the moisture of the ore is determined, on a large scale, by some conventional method, such as the drying of 1 or 2 lb in an open basin at 100° C., and weighing of the residue as dry ore. This is done at the sampling place by the firms concerned. The assayer further pounds up and mixes his sample, and then proceeds to determine the percentages of moisture and metal in his own way. He has always the choice between two methods, the dry and the wet. For the majority of gold or silver ores, and for cobalt and nickel ores almost as a rule, certain dry-process tests are preferred as the most exact analytically. In almost all other cases it may be said that the wet method is susceptible of the higher degree of precision, yet even in some of these cases the old dry-process tests are preferred to the present day. For instance, all copper ores in the British Isles are sold by the result of the Swansea assay, a kind of imitation of the process of sulphurous copper-ore smelting; and this, singularly, is adhered to even in the case of such cuprififerous materials as are worked by the wet way, although the Swansea assay is well known to lose about 1 per cent. of the copper present. A copper-smelter therefore had better buy 5 per cent. than 10 per cent. copper-pyrites cinders, because in the first case he pays only for four-fifths, while in the latter he must pay for nine-tenths of the copper present. To compensate for this anomaly, empirical methods have been contrived for calculating prices. (W. D.)

**METALS.** The earliest evidence of a knowledge and use of metals is found in the prehistoric implements of the so-called Bronze and Iron ages. In the earliest periods of written history, however, we meet with a number of metals in addition to these two. The Old Testament mentions six metals—gold, silver, copper, iron, tin, and lead. The Greeks, in addition to these and to bronze, came also to know mercury; and the same set of metals, without additions, forms the list of the Arabian chemists of the 8th and of the Western chemists of the 13th century. During the 15th century Basilius Valentinus discovered antimony; he also speaks of zinc and bismuth, but their individuality was established only at a later period. About 1730–40 the Swede Brand discovered arsenic and cobalt (the former is not reckoned a metal by modern chemists), while the Englishman Ward recognized the individuality of platinum. Nickel was discovered in 1774 by Cronstedt, manganese in 1774 by Scheele. The brothers D'Elhujart, in 1783, prepared tungsten; Hjelm, in 1782, isolated molybdenum from molybdic oxide, where

<sup>1</sup> For further information on slags, see Berthier, *Traité des essais par la voie sèche*; Winkler, *Erfahrungssätze über die Bildung der Schlacken*, Freiberg, 1827; Plattner, *Vorlesungen über allgemeine Hüttenkunde*, i. 28 sq.; Percy, *Metallurgy*.

its existence had been conjecturally asserted by Bergmann in 1781. Uranium, as a new element, was discovered by Klaproth in 1789; but his metallic "uranium," after having been accepted as a metal by all chemists until 1841, was then recognized as an oxide by Péligot, who subsequently isolated the true metal. Tellurium was discovered by Müller von Reichenbach in 1782 (again by Klaproth in 1798); titanium, by Klaproth in 1795; chromium, by Vauquelin in 1797; tantalum, by Hatchett in 1801, and by Ekeberg in 1802. Palladium, rhodium, iridium, and osmium (which four metals always accompany platinum in its ores) were discovered, the first two by Wollaston in 1803, the other two by a number of chemists; but their peculiarity was established chiefly by Smithson Tennant.

After Davy, in 1807 and 1808, had recognized the alkalies and alkaline earths as metallic oxides, the existence of metals in all basic earths became a foregone conclusion, which was verified sooner or later in all cases. But the discovery of aluminium by Wöhler in 1828, and that of magnesium by Bussy in 1829, claim special mention. Cadmium, a by no means rare heavy metal, was discovered only in 1818, by Stromeyer.

Of the large number of discoveries of rare metals which have been made in more recent times only a few can be mentioned, as marking new departures in research or offering other special points of interest. In 1861 Bunsen and Kirchhoff, by means of the method of spectrum analysis, which they had worked out shortly before, discovered two new alkali-metals which they called caesium and rubidium. By means of the same method Crookes, in 1861, discovered thallium; Reich and Richter, in 1863, indium; and Lecoq de Boisbaudran, in 1875, gallium. The existence of the last-named metal had been maintained, theoretically, by Mendelejeff, as early as 1871. The existence of vanadium was proved in 1830 by Sefström; but what he, and subsequently Berzelius, looked upon as the element was, in 1867, proved to be really an oxide by Roscoe, who also succeeded in isolating the true metal.

The development of earlier notions on the constitution of metals and their genetic relation to one another forms the most interesting chapter in the history of chemistry (see ALCHEMY). What modern science has to say on the matter is easily stated: all metals properly so called (i.e., all metals not alloys) are elementary substances; hence, chemically speaking, they are not "constituted" at all, and no two can be related to each other genetically in any way whatever. Our scientific instinct shrinks from embracing this proposition as final; but in the meantime it must be accepted as correctly formulating our ignorance on the subject. All metallic elements agree in this that they form each at least one basic oxide, or, what comes to the same thing, one chloride, stable in opposition to liquid water. This at once suggests an obvious definition of metals as a class of substances, but the definition would be highly artificial and objectionable on principle, because when we speak of metals we think, not of their accidental chemical relations, but of a certain sum of mechanical and physical properties which unites them all into one natural family. What these properties are we shall now endeavour to explain.

All metals, when exposed in an inert atmosphere to a sufficient temperature, assume the form of liquids, which all present the following characteristic properties. They are (at least practically) non-transparent; they reflect light in a peculiar manner, producing what is called "metallic lustre." When kept in non-metallic vessels they take the shape of a convex meniscus. These liquids, when exposed to higher temperatures, some sooner others later, pass into vapours. What these vapours are like is not known in many cases, since, as a rule, they can be produced only at