LINEN and **LINEN MANUFACTURES.** Under the name of linen are comprehended all yarns spun and fabrics woven from flax fibre (see FLAX).

From the earliest periods of human history till almost the close of the 18th century the linen manufacture was one of the most extensive and widely disseminated of the domestic industries of European countries. The industry was most largely developed in Russia, Austria, Germany, Holland, Belgium, the northern provinces of France, and certain parts of England, in the north of Ireland, and throughout Scotland; and in these countries its importance was generally recognized by the enactment of special laws, having for their object the protection and extension of the trade. The inventions of Arkwright, Hargreaves and Crompton in the later part of the 18th century, benefiting almost exclusively the art of cotton-spinning, and the unparalleled development of that branch of textile manufactures, largely due to the ingenuity of these inventors, gave the linen trade as it then existed a fatal blow. Domestic spinning, and with it hand-loom weaving, immediately began to shrink; the trade which had supported whole villages and provinces entirely disappeared, and the linen manufacture, in attenuated dimensions and changed conditions, took refuge in special localities, where it resisted, not unsuccessfully, the further assaults of cotton, and, with varying fortunes, rearranged its relations in the community of textile industries. The linen industries of the United Kingdom were the first to suffer from the aggression of cotton; more slowly the influence of the rival textile reached other countries.

In 1810 Napoleon I. offered a reward of one million francs to any inventor who should devise the best machinery for the spinning of flax yarn. Within a few weeks thereafter Philippe de Girard patented in France important inventions for flax spinning by both dry and wet methods. His inventions, however, did not receive the promised reward and were neglected in his native country. In 1815 he was invited by the Austrian government to establish a spinning mill at Hirtenberg near Vienna, which was run with his machinery for a number of years, but it failed to prove a commercial success. In the meantime English inventors had applied themselves to the task of adapting machines to the preparation and spinning of flax. The foundation of machine spinning of flax was laid by John Kendrew and Thomas Porthouse of Darlington, who, in 1787, secured a patent for "a mill or machine upon new principles for spinning yarn from hemp, tow, flax or wool." By innumerable successive improvements and modifications, the invention of Kendrew and Porthouse developed into the perfect system of machinery with which, at the present day, spinning-mills are furnished; but progress in adapting flax fibres for mechanical spinning, and linen yarn for weaving cloth by power-loom was much slower than in the corresponding case of cotton.

Till comparatively recent times, the sole spinning implements were the spindle and distaff. The spindle, which is the fundamental apparatus in all spinning machinery, was a round stick or rod of wood about 12 in. in length, tapering towards each extremity, and having at its upper end a notch or slit into which the yarn might be caught or fixed. In general, a ring or "whorl" of stone or clay was passed round the upper part of the spindle to give it momentum and steadiness when in rotation, while in some few cases an ordinary potato served the purpose of a whorl. The distaff, or rock, was a rather longer and stronger bar or stick, around one end of which, in a loose coil or ball, the fibrous material to be spun was wound. The other extremity of the distaff was carried under the left arm, or fixed in the girdle at the left side, so as to have the coil of flax in a convenient position for drawing out to form the yarn. A prepared end of yarn being fixed into the notch, the spinster, by a smart rolling motion of the spindle with the right hand against the right leg, threw it out from her, spinning in the air, while, with the left hand, she drew from the rock an additional supply of fibre which was formed into a uniform and equal strand with the right. The yarn being sufficiently twisted was released from the notch, wound around the lower part of the spindle, and again fixed in the notch at the point insufficiently twisted; and so the rotating, twisting and drawing out operations went on till the spindle was full. So persistent is an ancient and primitive art of this description that in remote districts of Scotland—a country where machine spinning has attained a high standard—spinning with rock and spindle is still practised;[1] and yarn of extraordinary delicacy, beauty and tenacity has been spun by their agency. The first improvement on the primitive spindle was found in the construction of the hand-wheel, in which the spindle, mounted in a frame, was fixed horizontally, and rotated by a band passing round it and a large wheel, set in the same framework. Such a wheel became known in Europe about the middle of the 16th century, but it appears to have been in use for cotton spinning in the East from time immemorial. At a later date, which cannot be fixed, the treadle motion was attached to the spinning wheel, enabling the spinster to sit at work with both hands free; and the introduction of the two-handed or double-spindle wheel, with flyers or twisting arms on the spindles, completed the series of mechanical improvements effected on flax spinning till the end of the 18th century. The common use of the two-handed wheel throughout the rural districts of Ireland and Scotland is a matter still within the recollection of some people; but spinning wheels are now seldom seen.

The modern manufacture of linen divides itself into two branches, spinning and weaving, to which may be added the bleaching and various finishing processes, which, in the case of many linen textures, are laborious undertakings and important branches of industry. The flax fibre is received in bundles from the scutch mill, and after having been classed into various grades, according to the quality of the material, it is labelled and placed in the store ready for the flax mill. The whole operations in yarn manufacture comprise (1) hackling, (2) preparing and (3) spinning.

Hackling.—This first preparatory process consists not only in combing out, disentangling and laying smooth and parallel the separate fibres, but also serves to split up and separate into their ultimate filaments the strands of fibre which, up to this point, have been agglutinated together. The hackling process was originally performed by hand, and it was one of fundamental importance, requiring the exercise of much dexterity and judgment. The broken, ravelled and short fibres, which separate out in the hackling process, form tow, an article of much inferior value to the spinner. A good deal of hand-hackling is still practised, especially in Irish and continental mills; and it has not been found practicable, in any case, to dispense entirely with a rough preparation of the fibre by hand labour. In hackling by hand, the hackler takes a handful or "strick" of rough flax, winds the top end around his hands, and then, spreading out the root end as broad and flat as possible, by a swinging motion dashes the fibre into the hackle teeth or needles of the rougher or "ruffer." The rougher is a board plated with tin, and studded with spikes or teeth of steel about 7 in. in length, which taper to a fine sharp point. The hackler draws his strick several times through this tool, working gradually up from the roots to near his hand, till in his judgment the fibres at the root end are sufficiently combed out and smoothed. He then seizes the root end and similarly treats the top end of the strick. The same process is again repeated on a similar tool, the teeth of which are 5 in. long, and much more closely studded together; and for the finer counts of yarn a third and a fourth hackle may be used, of still increasing fineness and closeness of teeth. In dealing with certain varieties of the fibre, for fine spinning especially, the flax is, after roughing, broken or cut into three lengths—the top, middle and root ends. Of these the middle cut is most valuable, being uniform in length, strength and quality. The root end is more woody and harsh, while the top, though fine in quality, is uneven and variable in strength. From some flax of extra length it is possible to take two short middle cuts; and, again, the fibre is occasionally only broken into two cuts. Flax so prepared is known as "cut line" in contradistinction to "long line" flax, which is the fibre unbroken. The subsequent treatment of line, whether long or cut, does not present sufficient variation to require further reference to these distinctions.

In the case of hackling by machinery, the flax is first roughed and arranged in stricks, as above described under hand hackling. In the construction of hackling machines, the general principles of those now most commonly adopted are identical. The machines are known as vertical sheet hackling machines, their essential features being a set of endless leather bands or sheets revolving over a pair of rollers in a vertical direction. These sheets are crossed by iron bars, to which hackle stocks, furnished with teeth, are screwed. The hackle stocks on each separate sheet are of one size and gauge, but each successive sheet in the length of the machine is furnished with stocks of increasing fineness, so that the hackling tool at the end where the flax is entered is the coarsest, say about four pins per inch, while that to which the fibre is last submitted has the smallest and most closely set teeth. The finest tools may contain from 45 to 60 pins per inch. Thus the whole of the endless vertical revolving sheet presents a continuous series of hackle teeth, and the machines are furnished with a double set of such sheets revolving face to face, so close together that the pins of one set of sheets intersect those on the opposite stocks. Overhead, and exactly centred between these revolving sheets, is the head or holder channel, from which the flax hangs down while it is undergoing the hackling process on both sides. The flax is fastened in a holder consisting of two heavy flat plates of iron, between which it is spread and tightly screwed up. The holder is 11 in. in length, and the holder channel is fitted to contain a line of six, eight or twelve such holders, according to the number of separate bands of hackling stocks in the machine. The head or holder channel has a falling and rising motion, by which it first presents the ends and gradually more and more of the length of the fibre to the hackle teeth, and, after dipping down the full length of the fibre exposed, it slowly rises and lifts the flax clear of the hackle stocks. By a reciprocal motion all the holders are then moved forward one length; that at the last and finest set of stocks is thrown out, and place is made for filling in an additional holder at the beginning of the series. Thus with a six-tool hackle, or set of stocks, each holder full of flax from beginning to end descends into and rises from the hackle teeth six times in travelling from end to end of the machine. The root ends being thus first hackled, the holders are shot back along an inclined plane, the iron plates unclamped, the flax reversed, and the top ends are then submitted to the same hackling operation. The tow made during the hackling

[1] See Sir Arthur Mitchell's *The Past in the Present* (Edinburgh, 1880).

process is carried down by the pins of the sheet, and is stripped from them by means of a circular brush placed immediately under the bottom roller. The brush revolves in the same direction as, but quicker than the sheet, consequently the tow is withdrawn from the pins. The tow is then removed from the brush by a doffer roller, from which it is finally removed by a doffing knife. This material is then carded by a machine similar to, but finer than, the one described under JUTE (*q.v.*). The hackled flax, however, is taken direct to the preparing department.

Preparing.—The various operations in this stage have for their object the proper assortment of dressed line into qualities fit for spinning, and the drawing out of the fibres to a perfectly level and uniform continuous ribbon or sliver, containing throughout an equal quantity of fibre in any given length. From the hackling the now smooth, glossy and clean stricks are taken to the sorting room, where they are assorted into different qualities by the "line sorter," who judges by both eye and touch the quality and capabilities of the fibre. So sorted, the material is passed to the spreading and drawing frames, a series or system of machines all similar in construction and effect. The essential features of the spreading frame are: (1) the feeding cloth or creeping sheet, which delivers the flax to (2) a pair of "feed and jockey" rollers, which pass it on (3) to the gill frame or fallers. The gill frame consists of a series of narrow hackle bars, with short closely studded teeth, which travel between the feed rollers and the drawing or "boss and pressing" rollers to be immediately attended to. They are, by an endless screw arrangement, carried forward at approximately the same rate at which the flax is delivered to them, and when they reach the end of their course they fall under, and by a similar screw arrangement are brought back to the starting-point; and thus they form an endless moving level toothed platform for carrying away the flax from the feed rollers. This is the machine in which the fibres are, for the first time, formed into a continuous length termed a sliver. In order to form this continuous sliver it is necessary that the short lengths of flax should overlap each other on the spread sheet or creeping sheet. This sheet contains four or six divisions, so that four or six lots of overlapped flax are moving at the same time towards the first pair of rollers—the boss rollers or retaining rollers. The fibre passes between these rollers and is immediately caught by the rising gills which carry the fibre towards the drawing rollers. The pins of the gills should pass through the fibre so that they may have complete control over it, while their speed should be a little greater than the surface speed of the retaining rollers. The fibre is thus carried forward to the drawing rollers, which have a surface speed of from 10 to 30 times that of the retaining rollers. The great difference between the speeds of the retaining and drawing rollers results in each sliver being drawn out to a corresponding degree. Finally all the slivers are run into one and in this state are passed between the delivery rollers into the sliver cans. Each can should contain the same length of sliver, a common length being 1000 yds. A bell is automatically rung by the machine to warn the attendant that the desired length has been deposited into the can. From the spreading frame the cans of sliver pass to the drawing frames, where from four to twelve slivers combined are passed through feed rollers over gills, and drawn out by drawing rollers to the thickness of one. A third and fourth similar doubling and drawing may be embraced in a preparing system, so that the number of doublings the flax undergoes, before it arrives at the roving frame, may amount to from one thousand to one hundred thousand, according to the quality of yarn in progress. Thus, for example, the doublings on one preparing system may be $6\times12\times12\times12\times8=82{,}944$. The slivers delivered by the last drawing frame are taken to the roving frame, where they are singly passed through feed rollers and over gills, and, after drafting to sufficient tenuity, they are slightly twisted by flyers and wound on bobbins, in which condition the material—termed "rove" or "rovings"—is ready for the spinning frame.[1]

Spinning.—The spinning operation, which follows the roving, is done in two principal ways, called respectively dry spinning and wet spinning, the first being used for the lower counts or heavier yarns, while the second is exclusively adopted in the preparation of fine yarns. The spinning frame does not differ in principle from the throstle spinning machine used in cotton manufacture. The bobbins of flax rove are arranged in rows on each side of the frame (the spinning frames being all double) on pins in an inclined plane. The rove passes downwards through an eyelet or guide to a pair of nipping rollers between which and the final drawing rollers, placed in the case of dry spinning from 18 to 22 in. lower down, the fibre receives its final draft while passing over and under cylinders and guide-plate, and attains that degree of tenuity which the finished yarn must possess. From the last rollers the now attenuated material, in passing to the flyers receives the degree of twist which compacts the fibres into the round hard cord which constitutes spun yarn; and from the flyers it is wound on the more slowly rotating spool within the flyer arms, centred on the top of the spindle. The amount of twist given to the thread at the spinning frame varies from 1·5 to 2 times the square root of the count. In wet spinning the general sequence of operations is the same, but the rove, as unwound from its bobbin, first passes through a trough of water heated to about 120° Fahr.; and the interval between the two pairs of rollers in which the drawing out of the rove is accomplished is very much shorter. The influence of the hot water on the flax fibre appears to be that it softens the gummy substance which binds the separate cells together, and thereby allows the elementary cells to a certain extent to be drawn out without breaking the continuity of the fibre; and further it makes a finer, smoother and more uniform strand than can be obtained by dry spinning. The extent to which the original strick of flax as laid on the feeding roller for (say) the production of a 50 lea yarn is, by doublings and drawings, extended, when it reaches the spinning spindle, may be stated thus: 35 times on spreading frame, 15 times on first drawing frame, 15 times on second drawing frame, 14 times on third drawing frame, 15 times on roving frame and 10 times on spinning frame, in all 16,537,500 times its original length, with $8\times12\times16=1536$ doublings on the three drawing frames. That is to say, 1 yd. of hackled line fed into the spreading frame is spread out, mixed with other fibres, to a length of about 9400 m. of yarn, when the above drafts obtain. The drafts are much shorter for the majority of yarns.

The next operation is reeling from the bobbins into hanks. By act of parliament, throughout the United Kingdom the standard measure of flax yard is the "lea," called also in Scotland the "cut" of 300 yds. The flax is wound or reeled on a reel having a circumference of 90 in. ($2\frac{1}{2}$ yds.) making "a thread," and one hundred and twenty such threads form a lea. The grist or count of all fine yarns is estimated by the number of leas in 1 lb; thus "50 lea" indicates that there are 50 leas or cuts of 300 yds. each in 1 lb of the yard so denominated. With the heavier yarns in Scotland the quality is indicated by their weight per "spyndle" of 48 cuts or leas; thus "3 lb tow yarn" is such as weighs 3 lb per spyndle, equivalent to "16 lea."

The hanks of yarn from wet spinning are either dried in a loft with artificial heat or exposed over ropes in the open air. When dry they are twisted back and forward to take the wiry feeling out of the yarn, and made up in bundles for the market as "grey yarn." English spinners make up their yarns into "bundles" of 20 hanks, each hank containing 10 leas; Irish spinners make hanks of 12 leas, $16\frac{2}{3}$ of which form a bundle; Scottish manufacturers adhere to the spyndle containing 4 hanks of 12 cuts or leas.

Commercial qualities of yarn range from about 8 lb tow yarns (6 lea) up to 160 lea line yarn. Very much finer yarn up even to 400 lea may be spun from the system of machines found in many mills; but these higher counts are only used for fine thread for sewing and for the making of lace. The highest counts of cut line flax are spun in Irish mills for the manufacture of fine cambrics and lawns which are characteristic features of the Ulster trade. Exceedingly high counts have sometimes been spun by hand, and for the preparation of the finest lace threads it is said the Belgian hand spinners must work in damp cellars, where the spinner is guided by the sense of touch alone, the filament being too fine to be seen by the eye. Such lace yarn is said to have been sold for as much as £240 per lb. In the Great Exhibition of 1851, yarn of 760 lea, equal to about 130 m. per lb, was shown which had been spun by an Irish woman eighty-four years of age. In the same exhibition there was shown by a Cambray manufacturing firm hand-spun yarn equal to 1200 warp and 1600 weft or to more than 204 and 272 m. per lb respectively.

Bleaching.—A large proportion of the linen yarn of commerce undergoes a more or less thorough bleaching before it is handed over to the weaver. Linen yarns in the green condition contain such a large proportion of gummy and resinous matter, removable by bleaching, that cloths which might present a firm close texture in their natural unbleached state would become thin and impoverished in a perfectly bleached condition. Nevertheless, in many cases it is much more satisfactory to weave the yarns in the green or natural colour, and to perform all bleaching operations in the piece. Manufacturers allow about 20 to 25% of loss in weight of yarn in bleaching from the green to the fully bleached stage; and the intermediate stages of boiled, improved, duck, cream, half bleach and three-quarters bleach, all indicating a certain degree of bleaching, have corresponding

[1] The preparation of tow for spinning differs in essential features from the processes above described. Tow from different sources, such as scutching tow, hackle tow, &c. differs considerably in quality and value, some being very impure, filled with woody shives, &c. while other kinds are comparatively open and clean. A preliminary opening and cleaning is necessary for the dirty much-matted tows, and in general thereafter they are passed through two carding engines called respectively the breaker and the finisher cards till the slivers from their processes are ready for the drawing and roving frames. In the case of fine clean tows, on the other hand, passing through a single carding engine may be sufficient. The processes which follow the carding do not differ materially from those followed in the preparation of rove from line flax.

degrees of loss in weight. The differences in colour resulting from different degrees of bleaching are taken advantage of for producing patterns in certain classes of linen fabrics.

Linen thread is prepared from the various counts of fine bleached line yarn by winding the hanks on large spools, and twisting the various strands, two, three, four or six cord as the case may be, on a doubling spindle similar in principle to the yarn spinning frame, excepting, of course, the drawing rollers. A large trade in linen thread has been created by its use in the machine manufacture of boots and shoes, saddlery and other leather goods, and in heavy sewing-machine work generally. The thread industry is largely developed at Lisburn near Belfast, at Johnstone near Glasgow, Bridport, Dorsetshire, and at Paterson, New Jersey, United States. Fine cords, net twine and ropes are also twisted from flax.

Weaving.—The difficulties in the way of power-loom linen weaving, combined with the obstinate competition of hand-loom weavers, delayed the introduction of factory weaving of linen fabrics for many years after the system was fully applied to other textiles. The principal difficulty arose through the hardness and inelasticity of the linen yarns, owing to which the yarn frequently broke under the tension to which it was subjected. Competition with the hand-loom against the power-loom in certain classes of work is conceivable, although it is absolutely impossible for the work of the spinning wheel to stand against the rivalry of drawing, roving and spinning frames. To the present day, in Ireland especially, a great deal of fine weaving is done by hand-loom. Warden states that power was applied on a small scale to the weaving of canvas in London about 1812; that in 1821 power-looms were started for weaving linen at Kirkcaldy, Scotland; and that in 1824 Maberly & Co. of Aberdeen had two hundred power-looms erected for linen manufacture. The power-loom has been in uninterrupted use in the Broadford factory, Aberdeen, which then belonged to Maberly & Co., down to the present day, and that firm may be credited with being the effective introducers of power-loom weaving in the linen trade.

The various operations connected with linen weaving, such as winding, warping, dressing, beaming and drawing-in, do not differ in essential features from the like processes in the case of cotton weaving, &c., neither is there any significant modification in the looms employed (see WEAVING). Dressing is a matter of importance in the preparation of linen warps for beaming. It consists in treating the spread yarn with flour or farina paste, applied to it by flannel-covered rollers, the lowermost of which revolves in a trough of paste. The paste is equalized on the yarn by brushes, and dried by passing the web over steam-heated cylinders before it is finally wound on the beam for weaving.

Fabrics. Linen fabrics are numerous in variety and widely different in their qualities, appearance and applications, ranging from heavy sail-cloth and rough sacking to the most delicate cambrics, lawns and scrims. The heavier manufactures include as a principal item sail-cloth, with canvas, tarpaulin, sacking and carpeting. The principal seats of the manufacture of these linens are Dundee, Arbroath, Forfar, Kirkcaldy, Aberdeen and Barnsley. The medium weight linens, which are used for a great variety of purposes, such as tent-making, towelling, covers, outer garments for men, linings, upholstery work, &c., include duck, huckaback, crash, tick, dowlas, osnaburg, low sheetings and low brown linens. Plain bleached linens form a class by themselves, and include principally the materials for shirts and collars and for bed sheets. Under the head of twilled linens are included drills, diapers and dimity for household use; and damasks for table linen, of which two kinds are distinguished—single or five-leaf damask, and double or eight-leaf damask, the pattern being formed by the intersection of warp and weft yarns at intervals of five and eight threads of yarn respectively. The fine linens are cambrics, lawns and handkerchiefs; and lastly, printed and dyed linen fabrics may be assigned to a special though not important class. In a general way it may be said regarding the British industry that the heavy linen trade centres in Dundee; medium goods are made in most linen manufacturing districts; damasks are chiefly produced in Belfast, Dunfermline and Perth; and the fine linen manufactures have their seat in Belfast and the north of Ireland. Leeds and Barnsley are the centres of the linen trade in England.

Linen fabrics have several advantages over cotton, resulting principally from the microscopic structure and length of the flax fibre. The cloth is much smoother and more lustrous than cotton cloth; and, presenting a less "woolly" surface, it does not soil so readily, nor absorb and retain moisture so freely, as the more spongy cotton; and it is at once a cool, clean and healthful material for bed-sheeting and clothing. Bleached linen, starched and dressed, possesses that unequalled purity, gloss and smoothness which make it alone the material suitable for shirt-fronts, collars and wristbands; and the gossamer delicacy, yet strength, of the thread it may be spun into fits it for the fine lace-making to which it is devoted. Flax is a slightly heavier material than cotton, while its strength is about double.

As regards the actual number of spindles and power-looms engaged in linen manufacture, the following particulars are taken from the report of the Flax Supply Association for 1905:—

Country.	Year.	Number of Spindles for Flax Spinning.	Year.	Number of Power-looms for Linen Weaving.
Austria-Hungary	1903	280,414	1895	3357
Belgium	1902	280,000	1900	3400
England and Wales	1905	49,941	1905	4424
France	1902	455,838	1891	18,083
Germany	1902	295,796	1895	7557
Holland	1896	8000	1891	1200
Ireland	1905	851,388	1905	34,498
Italy	1902	77,000	1902	3500
Norway	..	..	1880	120
Russia	1902	300,000	1889	7312
Scotland	1905	160,085	1905	17,185
Spain	..	..	1876	1000
Sweden	..	..	1884	286

British Exports of Linen Yarn and Cloth.

	1891.	1896.	1901.	1906.
Weight of linen yarn in pounds	14,859,900	18,462,300	12,971,100	14,978,200
Length in yards of linen piece goods, plain, bleached or unbleached	144,416,700	150,849,300	137,521,000	173,334,200
Length in yards of linen piece goods, checked, dyed or printed, also damask and diaper	11,807,600	17,986,100	8,007,600	13,372,100
Length in yards of sailcloth	3,233,400	5,372,600	4,686,700	4,251,400
Total length in yards of all kinds of linen cloth	159,457,700	174,208,000	150,215,300	190,957,700
Weight in pounds of linen thread for sewing	2,474,100	2,240,300	1,721,000	2,181,100

AUTHORITIES.—History of the trade, &c.: Warden's *Linen Trade, Ancient and Modern.* Spinning: Peter Sharp, *Flax, Tow and Jute Spinning* (Dundee); H. R. Carter, *Spinning and Twisting of Long Vegetable Fibres* (London). Weaving: Woodhouse and Milne, *Jute and Linen Weaving*, part i., Mechanism, part ii., Calculations and Cloth Structure (Manchester); and Woodhouse and Milne, *Textile Design: Pure and Applied* (London). (T. Wo.)