Laboratory Supply Company is now making some of these instruments to serve as reversible stereoscopes. In their manufacture the difficulties of projection of the two images to differently situated planes have been encountered, and have been met only by reducing this to a minimum and counting upon the fortunate property of the eyes to ignore or, indeed, to make terms of peace with this discrepancy. I find that this is easy, when an ordinary photograph with no sharp gradations of light and shade is used; but with diagrams the non-correspondence of top and bottom is moderately disturbing. I have not hesitated for purposes of convenience to combine lenses with this reflecting stereoscope; but I shall profit by Professor Whitman's suggestion to see how far the increased proximity of the eyes to the mirrors, which he recommends, will obtain certain of the advantages which I tried to secure by weak lenses. This last variation is a detail of construction in which Professor Whitman's device differs from mine.

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UNIVERSITY OF WISCONSIN,
April 8, 1905.

SPECIAL ARTICLES.

A REVISION OF THE COCCACEÆ.*

THE classification of the bacteria presents peculiar difficulties for several reasons. Morphological distinctions are so slight that physiological characters must necessarily be invoked in order to separate and classify the various organisms, and these physiological characters are often variable. Pathogenicity may be taken as a type of those powers of the organism which are easily and profoundly modified by external conditions. On the other hand, there are numerous characters which appear to be extremely constant. Such minute differences as occur in the resistance of different races to unfavorable conditions often remain unchanged through long periods of cultivation. In using these constant characters for classification we are met by another difficulty. Though constant, the differences are very minute, and in studying a number of organisms a perfect gradation is often found between the widest extremes. This is exactly what should be expected from organisms which reproduce only by asexual methods since it is the fusion of independent cells which swamps minor differences producing the uniformity of species among higher plants. With asexual reproduction every minute variation which is inheritable must persist unchanged until some other chance variation occurs. Each such variation means a new and different type of bacterium.

The immense number of generations which may succeed each other in a short space of time makes boundary lines as shifting as they would become among the higher plants if a dozen geological epochs were considered all at once.

Since with unicellular organisms acquired characters may probably be inherited in a higher degree than with other forms, existing races of bacteria will be markedly influenced by the selective effect of environmental conditions, and must bear the impress of their recent history.

There are, therefore, no species among the bacteria in quite the sense in which we ordinarily use the word,—as indicating a group of individuals bound together by a number of constant characters and easily identified by mutual fertility. From one point of view each distinct race might be considered a species; but to apply a name for every grade of difference in each varying character would be impracticable; and such names could have no true specific value. The best solution of the difficulty is the establishment of certain types around which the individual organisms may be more or less closely grouped; but it must be clearly recognized that the groups thus formed are defined by relation to the type at their center and are not sharply marked off at their extremities from the other groups adjacent.

It is impossible to make a natural classification of the bacteria, which shall be a true expression of phylogeny by considering a single character at a time,—for example, by dividing a group dichotomously, first according to mor-

* Preliminary communication. From the Biological laboratories of the Massachusetts Institute of Technology.

phology, then according to liquefaction, etc. Larger groups at least should manifestly be indicated by the collocation of several characters, the association of any two of which markedly strengthens their significance. By applying this principle, five fairly well-marked genera of coccaceæ may be distinguished. Four of these, *Sarcina, Micrococcus, Streptococcus* and *Ascococcus* date back to the early days of bacteriology, although the latter term has fallen into disuse. The mere property of zoöglea formation should not be considered of generic importance, but the few peculiar species which are capable of growing under purely saprophytic conditions and producing large gelatinous masses, are so far marked off from other cocci as to warrant, in our judgment, the retention of Cohn's genus. The genera *Micrococcus, Streptococcus* and *Sarcina* are retained, since in them morphological differences appear to be correlated with differences in biochemical characters or habitat and we have considerably enlarged the definitions of these genera to include physiological and ecological factors. With regard to the genus *Diplococcus* suggested by Weichselbaum for the parasite of pneumonia it should be remembered that any coccus may at times occur in pairs. Yet those organisms which are strictly parasitic and which normally occur only in aggregations of two cells appear to mark a valid group. The morphological character of a genus must never be too rigidly interpreted. It refers to the typical and most commonly characteristic growth forms; and other groupings may at times occur. Therefore, we recognize five genera, based in each case on a more or less constant association of several independent characteristics. The old genera *Merispomedia* and *Staphylococcus* are merely synonyms of Cohn's *Micrococcus,* and *Ascococcus* antedates *Leuconostoc.* Fischer's characterization of *Pediococcus* by regular division into two sections at right angles to each other, rests upon a variable and thoroughly artificial character and probably includes some species of *Micrococcus* and some imperfectly studied species of *Sarcina.*

With regard to the genera, *Planosarcina* and *Planococcus,* founded upon the single characteristic of the possession of flagella there may be more uncertainty. The slow revolution and steady translation observed by Ali-Cohen and Migula as associated with flagella, is certainly a phenomenon distinct from the irregular vibratory and rotary movements noted by other observers, but the resemblance between motile and non-motile forms is so close in all other characters that we can not consider this single property to be of generic importance.

The five genera above mentioned have been discussed first because their characteristics are already somewhat familiar; but in logical order the larger subdivisions should have been previously considered.

The family Coccaceæ, although defined only by the spherical form of the individual, is a thoroughly satisfactory natural group, its members being also marked off in certain physiological characters from individuals of other groups. The family appears to be divisible into two subfamilies. The first, for which we suggest the name Paracoccaceæ (paratrophic cocci), includes *Diplococcus* and *Streptococcus,* parasitic forms which do not develop abundant growth on artificial media and which thrive better under anaerobic than under aerobic conditions, and appear in small cell aggregates of pairs or chains. The second subfamily, the Metacoccaceæ (metatrophic cocci), includes *Micrococcus, Sarcina* and *Ascococcus,* saprophytic or semi-saprophytic types which are aerobic and form abundant surface growths of large cell groups.

The species of the coccaceæ are considerably more obscure. We have reviewed the descriptions of 445 supposedly distinct species given by Cohn, Migula, Flügge, Chester, Sternberg, Lehmann and Neumann, Engler and Prantl, Rabenhorst, Frankland and Woodhead and find a wonderful amount of duplication. Our observations have convinced us that minute differences in morphology, as for example, the distinction between large and small cells or long and short chains, are not sufficiently constant for the erection of species. Again, slight differences in the appearance of colonies on gelatin, which form a large number of German species, vary

so markedly, according to the composition of the medium and conditions of incubation, that they may be disregarded. The turbidity and sediment in broth varies with the age of the culture: what is first turbidity later settles to form sediment and those constant differences which do exist appear to be connected with the size of the cell aggregates. Organisms growing in large groups like most of the Sarcinæ produce heavy sediment and often colony-like groups on the walls of the tube, while those in which the cells readily separate exhibit a more diffuse turbidity. The growths on potato and Nährstoff agar are correlated with the general vigor of a particular race and vary markedly. Temperature relations are similarly inconstant and what marked differences exist are correlated with other characters to which we have given weight; for example, the Streptococci, as a rule, thrive best at the body temperature, while the Sarcinæ and many Micrococci grow better or as well at 20°.

There remain then for the establishment of species the relation of the organism to gelatin, its action upon sugars, its pigment production and its power to form nitrites and indol. In regard to all these points much more thorough study is needed. In particular, almost no data exist with regard to indol and nitrite production. By using the first three characters with one or two others which are of importance in special cases we have made a tentative division of the 445 described forms under thirty-one types. A careful comparison of the published descriptions furnished no evidence for more true species and 85 cultures, isolated from various sources, and obtained from the principal American laboratories, which we have studied in considerable detail, fall naturally under some one of the types established. *S. erysipelatos* includes 20 of these cultures, *M. aureus* 11, *M. orbicularis* 8, *M. ochraceus* 5, *M. ureæ* 3, *M. canescens* 5, *M. candicans* and *ventriculi* 2 each, *M. luteus, M. cinnabareus, M. æthebius, S. subflava, S. incarnata* and *S. aurantiaca* 1 each. It is very probable that our further investigation will warrant the division of some of these types but we present the thirty-one species below tentatively and subject to later revision. It must be understood as noted above that in all cases the names mark only types, numerous intermediate races existing between.

FAMILY COCCACEÆ.

Vegetative cells spherical.

Subfamily 1. PARACOCCACEÆ (*new subfamily*).

Parasites (thriving only, or best, on, or in the animal body). Thrive well under anaerobic conditions. Many forms fail to grow on artificial media, none produce abundant surface growths. Planes of fission generally parallel, producing pairs, or short or long chains.

Genus 1. *Diplococcus* (Weichselbaum).

Strict parasites. Not growing or growing very poorly, on artificial media. Cells normally in pairs, surrounded by a capsule.

Under *Diplococcus* are three species, *D. pneumoniæ*, Weich., *D. Weichselbaumii*, Trev. and *D. gonorrhœæ*, Neisser—distinguished by the tissue of the host affected, and by the peculiar morphology and staining reactions of the latter species.

Genus 2. *Streptococcus* (Billroth).

Parasites (see above). Cells normally in short or long chains (under unfavorable cultural conditions, sometimes in pairs and small groups—never in large groups or packets). On agar streak effused translucent growth often with isolated colonies. In stab culture, little surface growth. Sugars fermented with formation of acid.

Under *Streptococcus* we find the vast majority of organisms indistinguishable from *S. erysipelatos*, Fehleisen. Two varieties may perhaps be recognized, var. *involutus* Kurth; and var. *tenuis* (new variety), which fails to coagulate milk. Representatives of another species, *S. enteritidis* Escherich, which liquefies gelatin are occasionally found.

Subfamily 2. METACOCCACEÆ (*new subfamily*).

Facultative parasites or saprophytes. Thrive best under aerobic conditions. Grow well on artificial media, producing abundant surface growths. Planes of fission often at right angles; cells aggregated in groups, packets or zoöglea masses.

Genus 3. *Micrococcus* (Hallier) Cohn.

Facultative parasites or saprophytes. Cells in plates or irregular masses (never in long chains or packets). Acid production variable.

Under this genus, thirteen species may be distinguished, by the three properties of liquefaction, acid production and chromogenesis, their characters being indicated in tabular form below.

GELATIN LIQUEFIED.

	ACID.	NON-ACID.
Yellow	*M. aureus* (Ros.) Mig.	*M. orbicularis* (Ravenel)
White	*M. pyogenes* (Ros.) Mig.	*M. rhenanus* Mig.
Red	*M. roseus* Flügge.	*M. fulvus* Cohn.

GELATIN NOT LIQUEFIED.

	ACID.	NON-ACID.
Yellow	*M. luteus* (Schroter) Cohn.	*M. ochraceus* Rosenthal.
White	*M. candicans* Flügge.	*M. canescens* Mig.
Red		*M. cinnabareus* Flügge.

M. ureæ Cohn. Ammoniacal fermentation of urine produced. Gelatin not liquefied.

M. æthebius Trevisan. Ammoniacal fermentation of urine produced. Gelatin liquefied.

Genus 4. *Sarcina* (Goodsir).

Saprophytes or facultative parasites. Division under favorable conditions, in three planes, producing regular packets. Sugars as a rule not fermented.

Under *Sarcina* are eleven species, eight of which are grouped as follows:

	Gelatin Liquefied.	Gelatin not Liquefied.
Yellow	*S. subflava* Ravenel.	*S. ventriculi* Goodsir.
White	*S. candida* Lindner.	*S. pulmonum* Virchow.
Red	*S. rosacea* Lindner.	*S. incarnata* Gruber.
Brown	*S. cervina* Stub.	*S. fusca* Gruber.

In addition three somewhat aberrant species must be recognized—*S. aurantiaca* Flügge, a yellow liquefying chromogen, which unlike the other members of the group, has the power to coagulate milk, with *S. agilis* (Ali-Cohen) Mig. and *S. tetragenus* (Mendoza), Mig., respectively red, and yellowish-white, motile forms. From study of the literature and a few cultures of supposedly motile forms we are inclined to believe that all the truly motile cocci may be classed under these two heads.

Genus 5. *Ascococcus* (Cohn).

Generally saprophytic. Cells imbedded in large irregularly lobed masses of zoögloea, in presence of carbohydrates. Acid usually formed.

Two species are distinguished, *A. mesenteroides* Cienkowski, a non-liquefying form, and *A. mucilaginosus* Migula, a liquefier.

The characters of the species tentatively defined above are still somewhat artificial and may be subject to revision and modification when our studies are complete. It is probable that the liquefaction of gelatin can not bear any very direct relation to phylogeny, since in every genus except *Diplococcus,* and in each subdivision of a genus, a liquefying and a non-liquefying form occur parallel to each other.

Synonymy will be discussed in our full communication later; but we have strictly followed the rules of priority as recognized in other fields of systematic biology.

In reviewing our genera a serial arrangement is at once apparent. *Diplococcus* is strictly parasitic, and commonly produces only aggregates of two cells. *Streptococcus,* also normally parasitic, thrives better, though still not luxuriantly, on artificial media and its typical growth-form is a chain. *Micrococcus* includes both pathogenic and non-pathogenic forms but all grow abundantly on gelatin and agar, in rather large irregular cell aggregates, while some produce acid and some alkalies in milk. *Sarcina* shows further development in the same direction, its growth form being larger and produced by three planes of division, its saprophytic habit being more marked, (no truly pathogenic forms known to exist), with the power of acid production generally wanting. *Ascococcus,* in spite of its slight acid production and chain formation, appears on the whole to form the extreme of this series, since its entirely saprophytic existence and large vegetative growth-forms are far removed from the pathogenic micrococci. The genera above defined seem to mark the important transition stages beginning with such strict parasites as *D. Weichselbaumii* and ranging through the intermediate forms of Streptococci, Micrococci and Sarcinæ to the saprophytic *Ascococcus mesenteroides* at another extreme. We believe that these genera have true phylogenetic significance and represent real groups of organisms having natural affinities.

C.-E. A. Winslow,
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