

Using Table Automorphisms for Constructing Character Tables in GAP

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Abstract

This note has three aims. First it shows how character table automorphisms can be utilized to construct certain character tables from others using the GAP system [GAP04]; the GAP functions used for that are part of the GAP Character Table Library [Bre12]. Second it documents several constructions of character tables which are contained in the GAP Character Table Library. Third it serves as a testfile for the involved GAP functions.

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1 Overview

Several types of constructions of character tables of finite groups from known tables of smaller groups are described in Section 3. Selecting suitable character table automorphisms is an important ingredient of these constructions.

Section 2 collects the few representation theoretical facts on which these constructions are based.

The remaining sections show examples of the constructions in GAP. These examples use the GAP Character Table Library, therefore we load this package first.

```
gap> LoadPackage( "ctbllib", "1.1.4" );
true
```

2 Theoretical Background

2.1 Character Table Automorphisms

Let G be a finite group, $\text{Irr}(G)$ be the matrix of ordinary irreducible characters of G , $Cl(G)$ be the set of conjugacy classes of elements in G , g^G the G -conjugacy class of $g \in G$, and

$$pow_p: \begin{array}{ccc} Cl(G) & \rightarrow & Cl(G) \\ g^G & \mapsto & (g^p)^G \end{array}$$

the p -th power map, for each prime integer p .

A **table automorphism** of G is a permutation $\sigma: Cl(G) \rightarrow Cl(G)$ with the properties that $\chi \circ \sigma \in \text{Irr}(G)$ holds for all $\chi \in \text{Irr}(G)$ and that σ commutes with pow_p , for all prime integers p that divide the order of G . Note that for prime integers p that are coprime to the order of G , pow_p commutes with each σ that permutes $\text{Irr}(G)$, since pow_p acts as a field automorphism on the character values.

In GAP, a character table covers the irreducible characters –a matrix M of character values– as well as the power maps of the underlying group –each power map pow_p being represented as a list pow'_p of positive integers denoting the positions of the image classes. The group of table automorphisms of a character table is represented as a permutation group on the column positions of the table; it can be computed with the function `AutomorphismsOfTable`.

In the following, we will mainly use that each **group automorphism** σ of G induces a table automorphism that maps the class of each element in G to the class of its image under σ .

2.2 Permutation Equivalence of Character Tables

Two character tables with matrices M_1, M_2 of irreducibles and p -th power maps $pow_{1,p}, pow_{2,p}$ are *permutation equivalent* if permutations ψ and π of row and column positions of the M_i exist such that $[M_1]_{i,j} = [M_2]_{i\psi,j\pi}$ holds for all indices i, j , and such that $\pi \cdot pow'_{2,p} = pow'_{1,p} \cdot \pi$ holds for all primes p that divide the (common) group order. The first condition is equivalent to the existence of a permutation π such that permuting the columns of M_1 with π maps the set of rows of M_1 to the set of rows of M_2 .

π is of course determined only up to table automorphisms of the two character tables, that is, two transforming permutations π_1, π_2 satisfy that $\pi_1 \cdot \pi_2^{-1}$ is a table automorphism of the first table, and $\pi_1^{-1} \cdot \pi_2$ is a table automorphism of the second.

Clearly two isomorphic groups have permutation equivalent character tables.

The GAP library function `TransformingPermutationsCharacterTables` returns a record that contains transforming permutations of rows and columns if the two argument tables are permutation equivalent, and `fail` otherwise.

In the example sections, the following function for computing representatives from a list of character tables w.r.t. permutation equivalence will be used. More precisely, the input is either a list of character tables or a list of records which have a component `table` whose value is a character table, and the output is a sublist of the input.

```
gap> RepresentativesCharacterTables:= function( list )
>   local reps, i, found, r;
>
>   reps:= [];
>   for i in [ 1 .. Length( list ) ] do
>     if ForAll( reps, r -> ( IsCharacterTable( r ) and
>       TransformingPermutationsCharacterTables( list[i], r ) = fail )
>       or ( IsRecord( r ) and TransformingPermutationsCharacterTables(
>         list[i].table, r.table ) = fail ) ) then
>       Add( reps, list[i] );
>       fi;
>     od;
>   return reps;
> end;;
```

2.3 Class Fusions

For two groups H, G such that H is isomorphic with a subgroup of G , any embedding $\iota: H \rightarrow G$ induces a class function

$$fus_{\iota}: \begin{array}{ccc} Cl(H) & \rightarrow & Cl(G) \\ h^G & \mapsto & (\iota(h))^G \end{array}$$

the **class fusion** of H in G via ι . Analogously, for a normal subgroup N of G , any epimorphism $\pi: G \rightarrow G/N$ induces a class function

$$fus_{\pi}: \begin{array}{ccc} Cl(G) & \rightarrow & Cl(G/N) \\ g^G & \mapsto & (\pi(g))^G \end{array}$$

the **class fusion** of G onto G/N via π .

When one works only with character tables and not with groups, these class fusions are the objects that describe subgroup and factor group relations between character tables. Technically, class fusions are necessary for restricting, inducing, and inflating characters from one character table to another. If one is faced with the problem to compute the class fusion between the character tables of two groups H and G for which it is known that H can be embedded into G then one can use character-theoretic necessary conditions, concerning that the restriction of all irreducible characters of G to H (via the class fusion) must decompose into the irreducible characters of H , and that the class fusion must commute with the power maps of H and G .

With this character-theoretic approach, one can clearly determine possible class fusions only up to character table automorphisms. Note that one can interpret each character table automorphism of G as a class fusion from the table of G to itself.

If N is a normal subgroup in G then the class fusion of N in G determines the orbits of the conjugation action of G on the classes of N . Often the knowledge of these orbits suffices to identify the subgroup

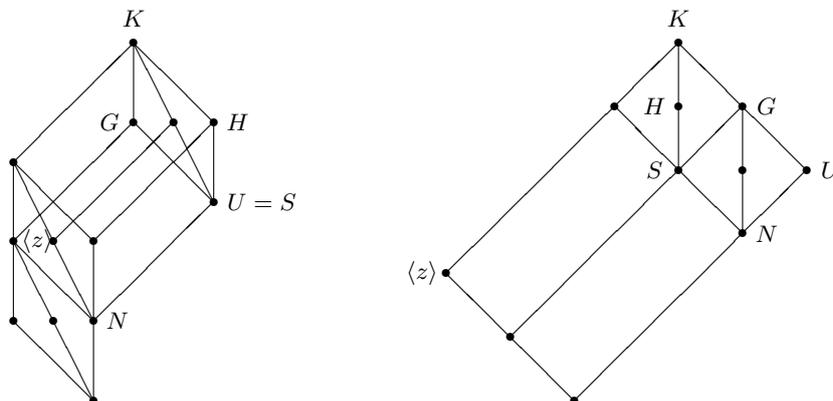
of table automorphisms of N that corresponds to this action of G ; for example, this is always the case if N has index 2 in G .

GAP library functions for dealing with class fusions, power maps, and character table automorphisms are described in the chapter “Maps Concerning Character Tables” in the GAP Reference Manual.

2.4 Constructing Character Tables of Certain Isoclinic Groups

As is stated in [CCN⁺85, p. xxiii], two groups G, H are called **isoclinic** if they can be embedded into a group K such that K is generated by $Z(K)$ and G , and also by $Z(K)$ and H . In the following, two special cases of isoclinism will be used, where the character tables of the isoclinic groups are closely related.

- (1) $G \cong 2 \times U$ for a group U that has a central subgroup N of order 2, and H is the central product of U and a cyclic group of order four. Here we can set $K = 2 \times H$.
- (2) $G \cong 2 \times U$ for a group U that has a normal subgroup N of index 2, and H is the subdirect product of U and a cyclic group of order four. Here we can set $K = 4 \times U$.



Starting from the group K containing both G and H , we first note that each irreducible representation of G or H extends to K . More specifically, if ρ_G is an irreducible representation of G then we can define an extension ρ of K by defining it suitably on $Z(K)$ and then form ρ_H , the restriction of ρ to H .

In our two cases, we set $S = G \cap H$, so $K = S \cup G \setminus S \cup H \setminus S \cup zS$ holds for some element $z \in Z(K) \setminus (G \cup H)$ of order four, and $G = S \cup gS$ for some $g \in G \setminus S$, and $H = S \cup hS$ where $h = z \cdot g \in H \setminus S$. For defining ρ_H , it suffices to consider $\rho(h) = \rho(z)\rho(g)$, where $\rho(z) = \epsilon_\rho(z) \cdot I$ is a scalar matrix.

As for the character table heads of G and H , we have $s^G = s^H$ and $z(g \cdot s)^G = (h \cdot s)^H$ for each $s \in S$, so this defines a bijection of the conjugacy classes of G and H . For a prime integer p , $(h \cdot s)^p = (z \cdot g \cdot s)^p = z^p \cdot (g \cdot s)^p$ holds for all $s \in S$, so the p -th power maps of G and H are related as follows: Inside S they coincide for any p . If $p \equiv 1 \pmod{4}$ they coincide also outside S , if $p \equiv -1 \pmod{4}$ the images differ by exchanging the classes of $(h \cdot s)^p$ and $z^2 \cdot (h \cdot s)^p$ (if these elements lie in different classes), and for $p = 2$ the images (which lie inside S) differ by exchanging the classes of $(h \cdot s)^2$ and $z^2 \cdot (g \cdot s)^2$ (if these elements lie in different classes).

Let ρ be an irreducible representation of K . Then ρ_G and ρ_H are related as follows: $\rho_G(s) = \rho_H(s)$ and $\rho(z) \cdot \rho_G(g \cdot s) = \rho_H(h \cdot s)$ for all $s \in S$. If χ_G and χ_H are the characters afforded by ρ_G and ρ_H , respectively, then $\chi_G(s) = \chi_H(s)$ and $\epsilon_\rho(z) \cdot \chi_G(g \cdot s) = \chi_H(h \cdot s)$ hold for all $s \in S$. In the case $\chi_G(z^2) = \chi(1)$ we have $\epsilon_\rho(z) = \pm 1$, and both cases actually occur if one considers all irreducible

representations of K . In the case $\chi_G(z^2) = -\chi(1)$ we have $\epsilon_\rho(z) = \pm i$, and again both cases occur. So we obtain the irreducible characters of H from those of G by multiplying the values outside S in all those characters by i that do not have z^2 in their kernels.

In GAP, the function `CharacterTableIsoclenic` can be used for computing the character table of H from that of G , and vice versa. (Note that in the above two cases, also the groups U and H are isoclinic by definition, but `CharacterTableIsoclenic` does not transfer the character table of U to that of H .)

2.5 Isoclinic Double Covers of Almost Simple Groups

`CharacterTableIsoclenic` can also be used to switch between the character tables of double covers of groups of the type $G.2$, where G is a perfect group, see [CCN⁺85, Section 6.7]. Typical examples are the double covers of symmetric groups.

Note that these double covers may be isomorphic. This happens for $2.S_6$. More generally, this happens for all semilinear groups $\Sigma L(2, p^2)$, for odd primes p . The smallest examples are $\Sigma L(2, 9) = 2.A_6.2_1$ and $\Sigma L(2, 25) = 2.L_2(25).2_2$. This implies that the character table and its isoclinic variant are permutation isomorphic.

```
gap> t:= CharacterTable( "2.A6.2_1" );
CharacterTable( "2.A6.2_1" )
gap> TransformingPermutationsCharacterTables( t,
>      CharacterTableIsoclenic( t ) );
rec( columns := (4,6)(5,7)(11,12)(14,16)(15,17),
      group := Group([ (16,17), (14,15) ]), rows := (3,5)(4,6)(10,11)(12,15,13,
      14) )
gap> t:= CharacterTable( "2.L2(25).2_2" );
CharacterTable( "2.L2(25).2_2" )
gap> TransformingPermutationsCharacterTables( t,
>      CharacterTableIsoclenic( t ) );
rec( columns := (7,9)(8,10)(20,21)(23,24)(25,27)(26,28),
      group := <permutation group with 4 generators>,
      rows := (3,5)(4,6)(14,15)(16,17)(19,22,20,21) )
```

For groups of the type $4.G.2$, two different situations can occur. Either the distinguished central cyclic subgroup of order four in $4.G$ is inverted by the elements in $4.G.2 \setminus 4.G$, or this subgroup is central in $4.G.2$. In the first case, calling `CharacterTableIsoclenic` with the character table of $4.G.2$ yields a character table with the same set of irreducibles, only the 2-power map will in general differ from that of the input table. In the second case, the one argument version of `CharacterTableIsoclenic` returns a permutation isomorphic table. By supplying additional arguments, there is a chance to construct tables of different groups.

We demonstrate this phenomenon with the various groups of the structure $4.L_3(4).2$.

```
gap> tbls:= [];
gap> for m in [ "4_1", "4_2" ] do
>   for a in [ "2_1", "2_2", "2_3" ] do
>     Add( tbls, CharacterTable( Concatenation( m, ".L3(4).", a ) ) );
>   od;
> od;
gap> tbls;
[ CharacterTable( "4_1.L3(4).2_1" ), CharacterTable( "4_1.L3(4).2_2" ),
  CharacterTable( "4_1.L3(4).2_3" ), CharacterTable( "4_2.L3(4).2_1" ),
  CharacterTable( "4_2.L3(4).2_2" ), CharacterTable( "4_2.L3(4).2_3" ) ]
gap> case1:= Filtered( tbls, t -> Size( ClassPositionsOfCentre( t ) ) = 2 );
```

```

[ CharacterTable( "4_1.L3(4).2_1" ), CharacterTable( "4_1.L3(4).2_2" ),
  CharacterTable( "4_2.L3(4).2_1" ), CharacterTable( "4_2.L3(4).2_3" ) ]
gap> case2:= Filtered( tbls, t -> Size( ClassPositionsOfCentre( t ) ) = 4 );
[ CharacterTable( "4_1.L3(4).2_3" ), CharacterTable( "4_2.L3(4).2_2" ) ]

```

The centres of the groups $4_1.L_3(4).2_1$, $4_1.L_3(4).2_2$, $4_2.L_3(4).2_1$, and $4_2.L_3(4).2_3$ have order two, that is, these groups belong to the first case. Each of these groups is not permutation equivalent to its isoclinic variant but has the same irreducible characters.

```

gap> isos1:= List( case1, CharacterTableIsoclinic );;
gap> List( [ 1 .. 4 ], i -> Irr( case1[i] ) = Irr( isos1[i] ) );
[ true, true, true, true ]
gap> List( [ 1 .. 4 ],
> i -> TransformingPermutationsCharacterTables( case1[i], isos1[i] ) );
[ fail, fail, fail, fail ]

```

The groups $4_1.L_3(4).2_3$ and $4_2.L_3(4).2_2$ belong to the second case because their centres have order four.

```

gap> isos2:= List( case2, CharacterTableIsoclinic );;
gap> List( [ 1, 2 ],
> i -> TransformingPermutationsCharacterTables( case2[i], isos2[i] ) );
[ rec( columns := (26,27,28,29)(30,31,32,33)(38,39,40,41)(42,43,44,45),
  group := <permutation group with 5 generators>,
  rows := (16,17)(18,19)(20,21)(22,23)(28,29)(32,33)(36,37)(40,41) ),
  rec( columns := (28,29,30,31)(32,33)(34,35,36,37)(38,39,40,41)(42,43,44,
  45)(46,47,48,49), group := <permutation group with 3 generators>,
  rows := (15,16)(17,18)(20,21)(22,23)(24,25)(26,27)(28,29)(34,35)(38,
  39)(42,43)(46,47) ) ]
gap> isos3:= List( case2, t -> CharacterTableIsoclinic( t,
> ClassPositionsOfCentre( t ) ) );;
gap> List( [ 1, 2 ],
> i -> TransformingPermutationsCharacterTables( case2[i], isos3[i] ) );
[ fail, fail ]

```

2.6 Characters of Normal Subgroups

Let G be a group and N be a normal subgroup of G . We will need the following well-known facts about the relation between the irreducible characters of G and N .

For an irreducible (Brauer) character χ of N and $g \in G$, we define χ^g by $\chi^g(n) = \chi(n^g)$ for all $n \in N$, and set $I_G(\chi) = \{g \in G; \chi^g = \chi\}$ (see [Fei82, p. 86]).

If $I_G(\chi) = N$ then the induced character χ^G is an irreducible (Brauer) character of G (see [Fei82, Lemma III 2.11]).

If G/N is cyclic and if $I_G(\chi) = G$ then $\chi = \psi_N$ for an irreducible (Brauer) character ψ of G , and each irreducible (Brauer) character θ with the property $\chi = \theta_N$ is of the form $\theta = \psi \cdot \epsilon$, where ϵ is an irreducible (Brauer) character of G/N (see [Fei82, Theorem III 2.14]).

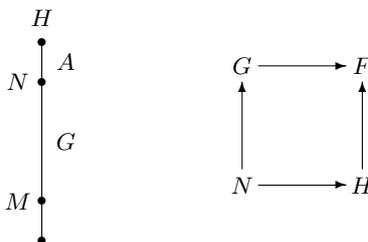
Clifford's theorem [Fei82, Theorem III 2.12] states that the restriction of an irreducible (Brauer) character of G to N has the form $e \sum_{i=1}^t \varphi_i$ for a positive integer e and irreducible (Brauer) characters φ_i of N , where t is the index of $I_G(\varphi_1)$ in G .

Now assume that G is a normal subgroup in a larger group H , that G/N is an abelian chief factor of H and that ψ is an ordinary irreducible character of G such that $I_H(\psi) = H$. Then either $t = 1$ and e^2 is one of 1, $|G/N|$, or $t = |G/N|$ and $e = 1$ (see [Isa76, Theorem 6.18]).

3 The Constructions

3.1 Character Tables of Groups of the Structure $M.G.A$

Let N denote a downward extension of the finite group G by a finite group M , let H denote an automorphic (upward) extension of N by a finite cyclic group A such that M is normal in H , and set $F = H/M$. We consider the situation that each irreducible character of N that does not contain M in its kernel induces irreducibly to H . Equivalently, the action of $A = \langle a \rangle$ on the characters of N , via $\chi \mapsto \chi^a$, has orbits of length exactly $|A|$ on the set $\{\chi \in \text{Irr}(N); M \not\subseteq \ker(\chi)\}$.



This occurs for example if M is central in N and A acts fixed-point freely on M , we have $|M| \equiv 1 \pmod{|A|}$ in this case. If M has prime order then it is sufficient that A does not centralize M .

The ordinary (or p -modular) irreducible characters of H are then given by the ordinary (or p -modular) irreducible characters of F and N , the class fusions from the table of N onto the table of G and from the table of G into that of F , and the permutation π that is induced by the action of A on the conjugacy classes of N .

In general, the action of A on the classes of M is not the right thing to look at, one really must consider the action on the relevant characters of $M.G$. For example, take H the quaternion group or the dihedral group of order eight, N a cyclic subgroup of index two, and M the centre of H ; here A acts trivially on M , but the relevant fact is that the action of A swaps those two irreducible characters of N that take the value -1 on the involution in M —these are the faithful irreducible characters of N .

If the orders of M and A are coprime then also the power maps of H can be computed from the above data. For each prime p that divides the orders of both M and A , the p -th power map is in general not uniquely determined by these input data. In this case, we can compute the (finitely many) candidates for the character table of H that are described by these data. One possible reason for ambiguities is the existence of several isoclinic but nonisomorphic groups that can arise from the input tables (cf. Section 2.4, see Section 4.10 for an example).

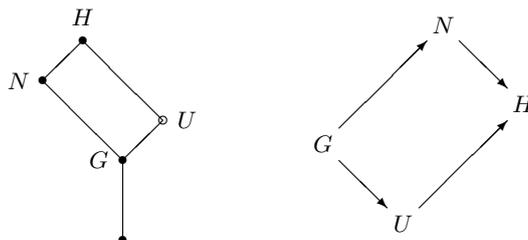
With the GAP function `PossibleActionsForTypeMGA`, one can compute the possible orbit structures induced by $G.A$ on the classes of $M.G$, and `PossibleCharacterTablesForTypeMGA` computes the possible ordinary character tables for a given orbit structure. For constructing the p -modular Brauer table of a group H of the structure $M.G.A$, the GAP function `BrauerTableOfTypeMGA` takes the ordinary character table of H and the p -modular tables of the subgroup $M.G$ and the factor group $G.A$ as its input. The p -modular table of G is not explicitly needed in the construction, it is implicitly given by the class fusions from $M.G$ into $M.G.A$ and from $M.G.A$ onto $G.A$; these class fusions must of course be available.

The GAP Character Table Library contains many tables of groups of the structure $M.G.A$ as described above, which are encoded by references to the tables of the groups $M.G$ and $G.A$, plus the fusion and action information. This reduces the space needed for storing these character tables.

For examples, see Section 4.

3.2 Character Tables of Groups of the Structure GS_3

Let G be a finite group, and H be an upward extension of G such that the factor group H/G is a Frobenius group $F = KC$ with abelian kernel K and cyclic complement C of prime order c . (Typical cases for F are the symmetric group S_3 on three points and the alternating group A_4 on four points.) Let N and U denote the preimages of K and C under the natural epimorphism from H onto F .



For certain isomorphism types of F , the ordinary (or p -modular) character table of H can be computed from the ordinary (or p -modular) character tables of G , U , and N , the class fusions from the table of G into those of U and N , and the permutation π induced by H on the conjugacy classes of N . This holds for example for $F = S_3$ and in the ordinary case also for $F = A_4$.

Each class of H is either a union of π -orbits or an H -class of $U \setminus G$; the latter classes are in bijection with the U -classes of $U \setminus G$, they are just $|K|$ times larger since the $|K|$ conjugates of U in H are fused. The power maps of H are uniquely determined from the power maps of U and N , because each element in F lies in K or in an F -conjugate of C .

Concerning the computation of the ordinary irreducible characters of H , we could induce the irreducible characters of U and N to H , and then take the union of the irreducible characters among those and the irreducible differences of those. (For the case $F = S_3$, this approach has been described in the Appendix of [HL94].)

The GAP function `CharacterTableOfTypeGS3` proceeds in a different way, which is suitable also for the construction of p -modular character tables of H .

By the facts listed in Section 2.6, for an irreducible (Brauer) character χ of N , we have $I_H(\chi)$ equal to either N or H . In the former case, χ induces irreducibly to H . In the latter case, there are extensions $\psi^{(i)}$, $1 \leq i \leq |C|$ (or $|C|_{p'}$), to H , and we have the following possibilities, depending on the restriction χ_G .

If $\chi_G = e\varphi$, for an irreducible character φ of G , then $I_U(\varphi) = U$ holds, hence the $\psi_U^{(i)}$ are $|C|$ (or $|C|_{p'}$) extensions of χ_G to U . Moreover, we have either $e = 1$ or $e^2 = |K|$. In the case $e = 1$, this determines the values of the $\psi^{(i)}$ on the classes of U outside G . In the case $e \neq 1$, we have the problem to combine e extensions of φ to a character of U that extends to H .

(One additional piece of information in the case of ordinary character tables is that the norm of this linear combination equals $1 + (|K| - 1)/|C|$, which determines the $\psi_U^{(i)}$ if $F = A_4 \cong 2^2 : 3$ or $F = 2^3 : 7$ holds; in the former case, the sum of each two out of the three different extensions of φ extends to U ; in the latter case, the sum of all different extensions plus one of the extensions extends. Note that for $F = S_3$, the case $e \neq 1$ does not occur.)

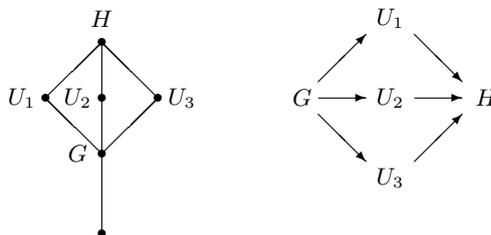
The remaining case is that χ_G is not a multiple of an irreducible character of G . Then $\chi_G = \varphi_1 + \varphi_2 + \dots + \varphi_{|K|}$, for pairwise different irreducible characters φ_i , $1 \leq i \leq |K|$, of G with the property $\varphi_i^N = \chi$. The action of U on G fixes at least one of the φ_i , since $|K| \equiv 1 \pmod{|C|}$. Without loss of generality, let $I_U(\varphi_1) = U$, and let $\tilde{\varphi}_1^{(i)}$, $1 \leq i \leq |C|$, be the extensions of φ_1 to U . (In fact exactly φ_1 is fixed by U since otherwise $k \in K$ would exist with $\varphi_1^k \neq \varphi_1$ and such that also φ_1^k would be invariant in U ; but then φ_1 would be invariant under both C and C^k , which generate F . So each of the $|K|$ constituents is invariant in exactly one of the $|K|$ subgroups of type U above G .)

Then $((\tilde{\varphi}_1^{(i)})^H)_N = \varphi_1^N = \chi$, hence the values of $\psi^{(i)}$ on the classes of $U \setminus G$ are given by those of $(\tilde{\varphi}_1^{(i)})^H$. (These are exactly the values of $\tilde{\varphi}_1^{(i)}$. So in both cases, we take the values of χ on N , and on the classes of $U \setminus G$ the values of the extensions of the unique extendible constituent of χ_G .)

For examples, see Section 5.

3.3 Character Tables of Groups of the Structure $G.2^2$

Let G be a finite group, and H be an upward extension of G such that the factor group H/G is a Klein four group. We assume that the ordinary character tables of G and of the three index two subgroups U_1, U_2 , and U_3 (of the structures $G.2_1, G.2_2$, and $G.2_3$, respectively) of H above G are known, as well as the class fusions of G into these groups. The idea behind the method that is described in this section is that in this situation, there are only few possibilities for the ordinary character table of H .



Namely, the action of H on the classes of $G.2_i$ is given by a table automorphism π_i of $G.2_i$, and H realizes compatible choices of such automorphisms π_1, π_2, π_3 in the sense that the orbits of all three π_i on the classes of G inside the groups $G.2_i$ coincide. Furthermore, if $G.2_i$ has n_i conjugacy classes then an action π_i that is a product of f_i disjoint transpositions leads to a character table candidate for $G.2^2$ that has $2n_i - 3f_i$ classes, so also the f_i must be compatible.

Taking the “inner” classes, i.e., the orbit sums of the classes inside G under the π_i , plus the union of the π_i -orbits of the classes of $G.2_i \setminus G$ gives a possibility for the classes of H . Furthermore, the power maps of the groups $G.2_i$ determine the power maps of the candidate table constructed this way.

Concerning the computation of the irreducible characters of H , we consider also the case of p -modular character tables, where we assume that the ordinary character table of H is already known and the only task is to compute the irreducible p -modular Brauer characters.

Let χ be an irreducible (p -modular Brauer) character of G . By the facts that are listed in Section 2.6, there are three possibilities.

1. $I_H(\chi) = G$; then χ^H is irreducible.
2. $I_H(\chi) = G.2_i$ for i one of 1, 2, 3; then $I_{G.2_i}(\chi) = G.2_i$ for this i , so χ extends to $G.2_i$; none of these extensions extends to H (because otherwise χ would be invariant in H), so they induce irreducible characters of H .
3. $I_H(\chi) = H$; then χ extends to each of the three groups $G.2_i$, and either all these extensions induce the same character of H (which vanishes on $H \setminus G$) or they are invariant in H and thus extend to H .

In the latter part of case 3. (except if $p = 2$), the problem is to combine the values of six irreducible characters of the groups $G.2_i$ to four characters of H . This yields essentially two choices, and we try to exclude one possibility by forming scalar products with the 2-nd symmetrizations of the known irreducibles. If several possibilities remain then we get several possible tables.

So we end up with a list of possible character tables of H .

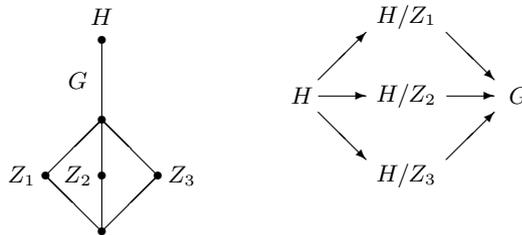
The first step is to specify a list of possible triples (π_1, π_2, π_3) , using the table automorphisms of the groups $G.2_i$; this can be done using the GAP function `PossibleActionsForTypeGV4`. Then the

GAP function `PossibleCharacterTablesOfTypeGV4` can be used for computing the character table candidates for each given triple of permutations; it may of course happen that some triples of automorphisms are excluded in this second step.

For examples, see Section 6.

3.4 Character Tables of Groups of the Structure $2^2.G$ (August 2005)

Let G be a finite group, and H be a central extension of G by a Klein four group $Z = \langle z_1, z_2 \rangle$; set $z_3 = z_1 z_2$ and $Z_i = \langle z_i \rangle$, for $1 \leq i \leq 3$. We assume that the ordinary character tables of the three factor groups $2_i.G = H/Z_i$ of H are known, as well as the class fusions from these groups to G . The idea behind the method described in this section is that in this situation, there are only few possibilities for the ordinary character table of H .



Namely, the irreducible (p -modular) characters of H are exactly the inflations of the irreducible (p -modular) characters of the three factor groups H/Z_i . (Note that for any noncyclic central subgroup C of H and any $\chi \in \text{Irr}(H)$, we have $|\ker(\chi) \cap C| > 1$. To see this, let $N = \ker(\chi)$. Then clearly $|N| > 1$, and χ can be regarded as a faithful irreducible character of H/N . If $N \cap C$ would be trivial then $NC/N \cong C$ would be a noncyclic central subgroup of H/N . This cannot happen by [Isa76, Thm. 2.32 (a)], so the statement can be regarded as an obvious refinement of this theorem.) So all we have to construct is the character table head of H –classes and power maps– and the factor fusions from H to these groups.

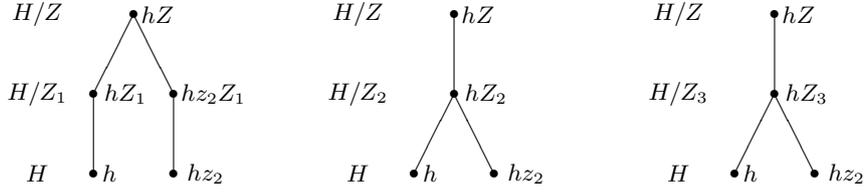
For fixed $h \in H$, we consider the question in which H -classes the elements h, hz_1, hz_2 , and hz_3 lie. There are three possibilities.

1. The four elements are all conjugate in H . Then in each of the three groups H/Z_i , the two preimages of $hZ \in H/Z$ are conjugate.
2. We are not in case 1. but two of the four elements are conjugate in H , i. e., $g^{-1}hg = hz_i$ for some $g \in H$ and some i ; then $g^{-1}hz_jg = hz_i z_j$ for each j , so the four elements lie in exactly two H -classes. This implies that for $i \neq j$, the elements h and hz_j are not H -conjugate, so hZ_i is not conjugate to $hz_j Z_i$ in H/Z_i and hZ_j is conjugate to $hz_i Z_j$ in H/Z_j .
3. The four elements are pairwise nonconjugate in H . Then in each of the three groups H/Z_i , the two preimages of $hZ \in H/Z$ are nonconjugate.

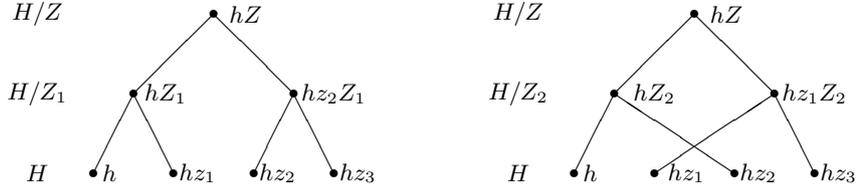
We observe that the question which case actually applies for $h \in H$ can be decided from the three factor fusions from H/Z_i to G . So we attempt to construct the table head of H and the three factor fusions from H to the groups H/Z_i , as follows. Each class g^G of G yields either one or two or four preimage classes in H .

In case 1., we get one preimage class in H , and have no choice for the factor fusions.

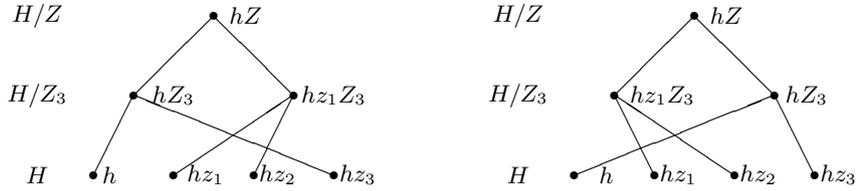
In case 2., we get two preimage classes, there is exactly one group H/Z_i in which g^G has two preimage classes –which are in bijection with the two preimage classes of H – and for the other two groups H/Z_j , the factor fusions from H map the two classes of H to the unique preimage class of g^G . (In the following picture, this is shown for $i = 1$.)



In case 3., the three factor fusions are in general not uniquely determined: We get four classes, which are defined as two pairs of preimages of the two preimages of g^G in H/Z_1 and in H/Z_2 – so we choose the relevant images in the two factor fusions to H/Z_1 and H/Z_2 , respectively. Note that the class of h in H is the unique class that maps to the class of hZ_1 in H/Z_1 and to the class of hZ_2 in H/Z_2 , and so on, and we define four classes of H via the four possible combinations of image classes in H/Z_1 and H/Z_2 (see the picture below).



Due to the fact that in general we do not know which of the two preimage classes of g^G in H/Z_3 is the class of hZ_3 , there are in general the following **two** possibilities for the fusion from H to H/Z_3 .



This means that we can inflate the irreducible characters of H/Z_1 and of H/Z_2 to H but that for the inflations of those irreducible characters of H/Z_3 to H that are not characters of G , the values on classes where case 3. applies are determined only up to sign.

The GAP function `PossibleCharacterTablesOfTypeV4G` computes the candidates for the table of H from the tables of the groups H/Z_i by setting up the character table head of H using the class fusions from H/Z_1 and H/Z_2 to G , and then forming the possible class fusions from H to H/Z_3 .

If case 3. applies for a class g^G with g of **odd** element order then exactly one preimage class in H has odd element order, and we can identify this class in the groups H/Z_i , which resolves the ambiguity in this situation. More generally, if $g = k^2$ holds for some $k \in G$ then all preimages of k^G in H square to the same class of H , so again this class can be identified. In fact `PossibleCharacterTablesOfTypeV4G` checks whether the p -th power maps of the candidate table for H and the p -th power map of H/Z_3 together with the fusion candidate form a commutative diagram.

An additional criterion used by `PossibleCharacterTablesOfTypeV4G` is given by the property that the product of two characters inflated from H/Z_1 and H/Z_2 , respectively, that are not characters of G is a character of H that contains Z_3 in its kernel, so it is checked whether the scalar products of these

characters with all characters that are inflated from H/Z_3 via the candidate fusion are nonnegative integers.

Once the fusions from H to the groups H/Z_i are known, the computation of the irreducible p -modular characters of H from those of the groups H/Z_i is straightforward.

The only open question is why this construction is described in this note. That is, how is it related to table automorphisms?

The answer is that in several interesting cases, the three subgroups Z_1, Z_2, Z_3 are conjugate under an order three automorphism σ , say, of H . In this situation, the three factor groups $2_i.G = H/Z_i$ are isomorphic, and we can describe the input tables and fusions by the character table of $2_1.G$, the factor fusion from this group to G , and the automorphism $\bar{\sigma}$ of G that is induced by σ . Assume that $\sigma(Z_1) = Z_2$ holds, and choose $h \in H$. Then $\sigma(hZ_1) = \sigma(h)Z_2$ is mapped to $\sigma(h)Z = \bar{\sigma}(hZ)$ under the factor fusion from $2_2.G$ to G . Let us start with the character table of $2_1.G$, and fix the class fusion to the character table of G . We may choose the identity map as isomorphism from the table of $2_1.G$ to the tables of $2_2.G$ and $2_3.G$, which implies that the class of hZ_1 is identified with the class of hZ_2 and in turn the class fusion from the table of $2_2.G$ to that of G can be chosen as the class fusion from the table of $2_1.G$ followed by the permutation of classes of G induced by $\bar{\sigma}$; analogously, the fusion from the table of $2_3.G$ is obtained by applying this permutation twice to the class fusion from the table of $2_1.G$.

For examples, see Section 7.

3.5 p -Modular Tables of Extensions by p -singular Automorphisms

Let G be a finite group, and H be an upward extension of G by an automorphism of prime order p , say. H induces a table automorphism of the p -modular character table of G ; let π denote the corresponding permutation of classes of G . The columns of the p -modular character table of H are given by the orbits of π , and the irreducible Brauer characters of H are exactly the orbit sums of π on the irreducible Brauer characters of G .

Note that for computing the p -modular character table of H from that of G , it is sufficient to know the orbits of π and not π itself. Also the ordinary character table of H is not needed, but since GAP stores Brauer character tables relative to their ordinary tables, we are interested mainly in cases where the ordinary character tables of G and H and the p -modular character table of G are known. Assuming that the class fusion between the ordinary tables of G and H is stored on the table of G , the orbits of the action of H on the p -regular classes of G can be read off from it.

The GAP function `IBrOfExtensionBySingularAutomorphism` can be used to compute the p -modular irreducibles of H .

For examples, see Section 8.

3.6 Character Tables of Subdirect Products of Index Two (July 2007)

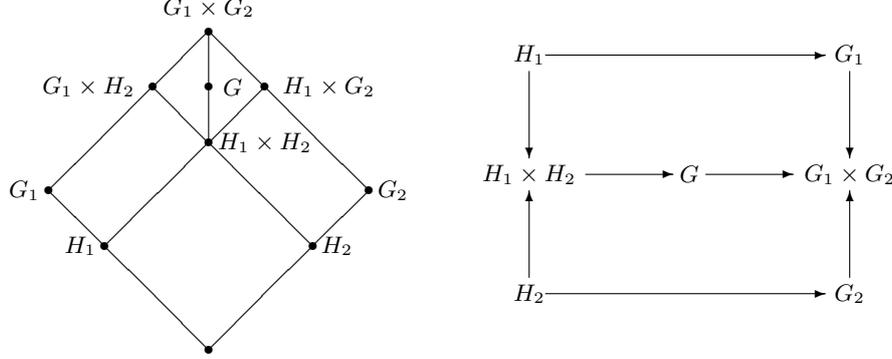
Let C_2 denote the cyclic group of order two, let G_1, G_2 be two finite groups, and for $i \in \{1, 2\}$, let $\varphi_i: G_i \rightarrow C_2$ be an epimorphism with kernel H_i . Let G be the subdirect product (pullback) of G_1 and G_2 w.r.t. the epimorphisms φ_i , i.e.,

$$G = \{(g_1, g_2) \in G_1 \times G_2; \varphi_1(g_1) = \varphi_2(g_2)\}.$$

The group G has index two in the direct product $G_1 \times G_2$, and G contains $H_1 \times H_2$ as a subgroup of index two.

In the following, we describe how the ordinary (or p -modular) character table of G can be computed from the ordinary (or p -modular) character tables of the groups G_i and H_i , and the class fusions from H_i to G_i .

(For the case that one of the groups G_i is a cyclic group of order four, an alternative way to construct the character table of G is described in Section 2.4. For the case that one of the groups G_i acts fixed point freely on the nontrivial irreducible characters of H_i , an alternative construction is described in Section 3.1.)



Each conjugacy class of G is either contained in $H_1 \times H_2$ or not. In the former case, let $h_i \in H_i$ and $g_i \in G_i \setminus H_i$; in particular, $(g_1, g_2) \in G$ because both $\varphi_1(g_1)$ and $\varphi_2(g_2)$ are not the identity. There are four possibilities.

1. If $h_1^{H_1} = h_1^{G_1}$ and $h_2^{H_2} = h_2^{G_2}$ then $(h_1, h_2)^{H_1 \times H_2} = (h_1, h_2)^{G_1 \times G_2}$ holds, hence this class is equal to $(h_1, h_2)^G$.
2. If $h_1^{H_1} \neq h_1^{G_1}$ and $h_2^{H_2} \neq h_2^{G_2}$ then the four $H_1 \times H_2$ -classes with the representatives (h_1, h_2) , $(h_1^{g_1}, h_2)$, $(h_1, h_2^{g_2})$, and $(h_1^{g_1}, h_2^{g_2})$ fall into two G -classes, where (h_1, h_2) is G -conjugate with $(h_1^{g_1}, h_2^{g_2})$, and $(h_1^{g_1}, h_2)$ is G -conjugate with $(h_1, h_2^{g_2})$.
3. If $h_1^{H_1} = h_1^{G_1}$ and $h_2^{H_2} \neq h_2^{G_2}$ then the two $H_1 \times H_2$ -classes with the representatives (h_1, h_2) and $(h_1, h_2^{g_2})$ fuse in G ; note that there is $\tilde{g}_1 \in C_{G_1}(h_1) \setminus H_1$, so $(\tilde{g}_1, g_2) \in G$ holds.
4. The case of $h_1^{H_1} \neq h_1^{G_1}$ and $h_2^{H_2} = h_2^{G_2}$ is analogous to case 3.

It remains to deal with the G -classes that are not contained in $H_1 \times H_2$. Each such class is in fact a conjugacy class of $G_1 \times G_2$. Note that two elements $g_1, g_2 \in G_1 \setminus H_1$ are G_1 -conjugate if and only if they are H_1 -conjugate. (If $g_1^x = g_2$ for $x \in G_1 \setminus H_1$ then $g_1^{g_1^x} = g_2$ holds, and $g_1 x \in H_1$.) This implies $(g_1, g_2)^{G_1 \times G_2} = (g_1, g_2)^{H_1 \times H_2}$, and thus this class is equal to $(g_1, g_2)^G$.

The (ordinary or p -modular) irreducible characters of G are given by the restrictions χ_G of all those irreducible characters χ of $G_1 \times G_2$ whose restriction to $H_1 \times H_2$ is irreducible, plus the induced characters φ^G , where φ runs over all those irreducible characters of $H_1 \times H_2$ that do not occur as restrictions of characters of $G_1 \times G_2$.

In other words, no irreducible character of $H_1 \times H_2$ has inertia subgroup G inside $G_1 \times G_2$. This can be seen as follows. Let φ be an irreducible character of $H_1 \times H_2$. Then $\varphi = \varphi_1 \cdot \varphi_2$, where φ_1, φ_2 are irreducible characters of $H_1 \times H_2$ with the properties that $H_2 \subseteq \ker(\varphi_1)$ and $H_1 \subseteq \ker(\varphi_2)$. Sloppy speaking, φ_i is an irreducible character of H_i .

There are four possibilities.

1. If φ_1 extends to G_1 and φ_2 extends to G_2 then φ extends to G , so φ has inertia subgroup $G_1 \times G_2$.
2. If φ_1 does not extend to G_1 and φ_2 does not extend to G_2 then $\varphi^{G_1 \times G_2}$ is irreducible, so φ has inertia subgroup $H_1 \times H_2$.
3. If φ_1 extends to G_1 and φ_2 does not extend to G_2 then φ extends to $G_1 \times H_2$ but not to $G_1 \times G_2$, so φ has inertia subgroup $G_1 \times H_2$.
4. The case that φ_1 does not extend to G_1 and φ_2 extends to G_2 is analogous to case 3, φ has inertia subgroup $H_1 \times G_2$.

For examples, see Section 9.

4 Examples for the Type $M.G.A$

4.1 Character Tables of Dihedral Groups

Let $n = 2^k \cdot m$ where k is a nonnegative integer and m is an odd integer, and consider the dihedral group D_{2n} of order $2n$. Let N denote the derived subgroup of D_{2n} .

If $k = 0$ then D_{2n} has the structure $M.G.A$, with $M = N$ and G the trivial group, and A a cyclic group of order two that inverts each element of N and hence acts fixed-point freely on N . The smallest nontrivial example is of course that of $D_6 \cong S_3$.

```
gap> tblMG:= CharacterTable( "Cyclic", 3 );;
gap> tblG:= CharacterTable( "Cyclic", 1 );;
gap> tblGA:= CharacterTable( "Cyclic", 2 );;
gap> StoreFusion( tblMG, [ 1, 1, 1 ], tblG );
gap> StoreFusion( tblG, [ 1 ], tblGA );
gap> elms:= Elements( AutomorphismsOfTable( tblMG ) );
[ (), (2,3) ]
gap> orbs:= [ [ 1 ], [ 2, 3 ] ];;
gap> new:= PossibleCharacterTablesOfTypeMGA( tblMG, tblG, tblGA, orbs,
> "S3" );
[ rec( MGfusMGA := [ 1, 2, 2 ], table := CharacterTable( "S3" ) ) ]
gap> Display( new[1].table );
S3
```

```
  2  1  .  1
  3  1  1  .
```

```
  1a 3a 2a
2P 1a 3a 1a
3P 1a 1a 2a
```

```
X.1  1  1  1
X.2  1  1 -1
X.3  2 -1  .
```

If $k > 0$ then D_{2n} has the structure $M.G.A$, with $M = N$ and G a cyclic group of order two such that $M.G$ is cyclic, and A is a cyclic group of order two that inverts each element of $M.G$ and hence acts fixed-point freely on $M.G$. The smallest nontrivial example is of course that of D_8 .

```
gap> tblMG:= CharacterTable( "Cyclic", 4 );;
gap> tblG:= CharacterTable( "Cyclic", 2 );;
gap> tblGA:= CharacterTable( "2^2" );;
gap> OrdersClassRepresentatives( tblMG );
[ 1, 4, 2, 4 ]
gap> StoreFusion( tblMG, [ 1, 2, 1, 2 ], tblG );
gap> StoreFusion( tblG, [ 1, 2 ], tblGA );
gap> elms:= Elements( AutomorphismsOfTable( tblMG ) );
[ (), (2,4) ]
gap> orbs:= Orbits( Group( elms[2] ), [ 1 ..4 ] );;
gap> new:= PossibleCharacterTablesOfTypeMGA( tblMG, tblG, tblGA, orbs,
> "order8" );
[ rec( MGfusMGA := [ 1, 2, 3, 2 ], table := CharacterTable( "order8" ) ),
  rec( MGfusMGA := [ 1, 2, 3, 2 ], table := CharacterTable( "order8" ) ) ]
```

Here we get two possible tables, which are the character tables of the dihedral and the quaternion group of order eight, respectively.

```
gap> List( new, x -> OrdersClassRepresentatives( x.table ) );
[ [ 1, 4, 2, 2, 2 ], [ 1, 4, 2, 4, 4 ] ]
gap> Display( new[1].table );
order8
```

2	3	2	3	2	2
	1a	4a	2a	2b	2c
2P	1a	2a	1a	1a	1a

X.1	1	1	1	1	1
X.2	1	1	1	-1	-1
X.3	1	-1	1	1	-1
X.4	1	-1	1	-1	1
X.5	2	.	-2	.	.

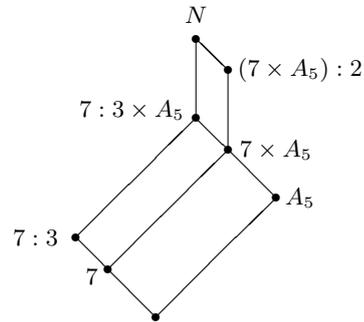
For each $k > 1$ and $m = 1$, we get two possible tables this way, that of the dihedral group of order 2^{k+1} and that of the generalized quaternion group of order 2^{k+1} .

4.2 An $M.G.A$ Type Example with M noncentral in $M.G$ (May 2004)

The Sylow 7 normalizer in the symmetric group S_{12} has the structure $7 : 6 \times S_5$, its intersection N with the alternating group A_{12} is of index two, it has the structure $(7 : 3 \times A_5) : 2$.

Let M denote the normal subgroup of order 7 in N , let G denote the normal subgroup of the type $3 \times A_5$ in $F = N/M \cong 3 \times S_5$, and $A = F/G$, the cyclic group of order two. Then N has the structure $M.G.A$, where A acts fixed-point freely on the irreducible characters of $M.G = 7 : 3 \times A_5$ that do not contain M in their kernels, hence the character table of N is determined by the character tables of $M.G$ and F , and the action of A on $M.G$.

Note that in this example, the group M is not central in $M.G$, unlike in most of our examples.



```
gap> tblMG:= CharacterTable( "7:3" ) * CharacterTable( "A5" );;
gap> nsg:= ClassPositionsOfNormalSubgroups( tblMG );
[ [ 1 ], [ 1, 6 .. 11 ], [ 1 .. 5 ], [ 1, 6 .. 21 ], [ 1 .. 15 ], [ 1 .. 25 ]
]
gap> List( nsg, x -> Sum( SizesConjugacyClasses( tblMG ){ x } ) );
[ 1, 7, 60, 21, 420, 1260 ]
gap> tblG:= tblMG / nsg[2];;
gap> tblGA:= CharacterTable( "Cyclic", 3 ) * CharacterTable( "A5.2" );;
gap> GfusGA:= PossibleClassFusions( tblG, tblGA );
[ [ 1, 2, 3, 4, 4, 8, 9, 10, 11, 11, 15, 16, 17, 18, 18 ],
  [ 1, 2, 3, 4, 4, 15, 16, 17, 18, 18, 8, 9, 10, 11, 11 ] ]
gap> reps:= RepresentativesFusions( Group(), GfusGA, tblGA );
[ [ 1, 2, 3, 4, 4, 8, 9, 10, 11, 11, 15, 16, 17, 18, 18 ] ]
gap> StoreFusion( tblG, reps[1], tblGA );
```

```

gap> acts:= PossibleActionsForTypeMGA( tblMG, tblG, tblGA );
[ [ [ 1 ], [ 2 ], [ 3 ], [ 4, 5 ], [ 6, 11 ], [ 7, 12 ], [ 8, 13 ],
    [ 9, 15 ], [ 10, 14 ], [ 16 ], [ 17 ], [ 18 ], [ 19, 20 ], [ 21 ],
    [ 22 ], [ 23 ], [ 24, 25 ] ] ]
gap> poss:= PossibleCharacterTablesOfTypeMGA( tblMG, tblG, tblGA,
>      acts[1], "A12N7" );
[ rec( MGFusMGA := [ 1, 2, 3, 4, 4, 5, 6, 7, 8, 9, 5, 6, 7, 9, 8, 10, 11, 12,
    13, 13, 14, 15, 16, 17, 17 ], table := CharacterTable( "A12N7" ) ) ]

```

Let us compare the result table with the table of the Sylow 7 normalizer in A_{12} .

```

gap> g:= AlternatingGroup( 12 );;
gap> IsRecord( TransformingPermutationsCharacterTables( poss[1].table,
>      CharacterTable( Normalizer( g, SylowSubgroup( g, 7 ) ) ) ) );
true

```

Since July 2007, an alternative way to construct the character table of N from other character tables is to exploit its structure as a subdirect product of index two in the group $7 : 6 \times S_5$, see Section 3.6.

```

gap> tblh1:= CharacterTable( "7:3" );;
gap> tblg1:= CharacterTable( "7:6" );;
gap> tblh2:= CharacterTable( "A5" );;
gap> tblg2:= CharacterTable( "A5.2" );;
gap> subdir:= CharacterTableOfIndexTwoSubdirectProduct( tblh1, tblg1,
>      tblh2, tblg2, "(7:3xA5).2" );;
gap> IsRecord( TransformingPermutationsCharacterTables( poss[1].table,
>      subdir.table ) );
true

```

For storing the table of N in the GAP Character Table Library, the construction as a subdirect product is more suitable, since the “auxiliary table” of the direct product $7 : 3 \times A_5$ need not be stored in the library.

4.3 Atlas Tables of the Type $M.G.A$

We show the construction of some character tables of groups of the type $M.G.A$ that are contained in the GAP Character Table Library. Each entry in the following input list contains the names of the library character tables of $M.G$, G , $G.A$, and $M.G.A$.

First we consider the situation where G is a simple group or a central extension of a simple group whose character table is shown in the ATLAS, and M and A are cyclic groups such that M is central in $M.G$.

In the following cases, the character tables are uniquely determined by the input tables. Note that in each of these cases, $|A|$ and $|M|$ are coprime.

```

gap> listMGA:= [
> [ "3.A6",      "A6",      "A6.2_1",      "3.A6.2_1"    ],
> [ "3.A6",      "A6",      "A6.2_2",      "3.A6.2_2"    ],
> [ "6.A6",      "2.A6",      "2.A6.2_1",    "6.A6.2_1"    ],
> [ "6.A6",      "2.A6",      "2.A6.2_2",    "6.A6.2_2"    ],
> [ "3.A7",      "A7",        "A7.2",        "3.A7.2"      ],
> [ "6.A7",      "2.A7",      "2.A7.2",      "6.A7.2"      ],
> [ "3.L3(4)",   "L3(4)",     "L3(4).2_2",   "3.L3(4).2_2" ],
> [ "3.L3(4)",   "L3(4)",     "L3(4).2_3",   "3.L3(4).2_3" ],
> [ "6.L3(4)",   "2.L3(4)",   "2.L3(4).2_2", "6.L3(4).2_2" ],

```

```

> [ "6.L3(4)",      "2.L3(4)",      "2.L3(4).2_3",    "6.L3(4).2_3"    ],
> [ "12_1.L3(4)",  "4_1.L3(4)",    "4_1.L3(4).2_2",  "12_1.L3(4).2_2" ],
> [ "12_1.L3(4)",  "4_1.L3(4)",    "4_1.L3(4).2_3",  "12_1.L3(4).2_3" ],
> [ "12_2.L3(4)",  "4_2.L3(4)",    "4_2.L3(4).2_2",  "12_2.L3(4).2_2" ],
> [ "12_2.L3(4)",  "4_2.L3(4)",    "4_2.L3(4).2_3",  "12_2.L3(4).2_3" ],
> [ "3.U3(5)",     "U3(5)",        "U3(5).2",        "3.U3(5).2"      ],
> [ "3.M22",       "M22",          "M22.2",          "3.M22.2"        ],
> [ "6.M22",       "2.M22",        "2.M22.2",        "6.M22.2"        ],
> [ "12.M22",      "4.M22",        "4.M22.2",        "12.M22.2"       ],
> [ "3.L3(7)",     "L3(7)",        "L3(7).2",        "3.L3(7).2"      ],
> [ "3_1.U4(3)",   "U4(3)",        "U4(3).2_1",      "3_1.U4(3).2_1"  ],
> [ "3_1.U4(3)",   "U4(3)",        "U4(3).2_2",      "3_1.U4(3).2_2"  ],
> [ "3_2.U4(3)",   "U4(3)",        "U4(3).2_1",      "3_2.U4(3).2_1"  ],
> [ "3_2.U4(3)",   "U4(3)",        "U4(3).2_3",      "3_2.U4(3).2_3"  ],
> [ "6_1.U4(3)",   "2.U4(3)",      "2.U4(3).2_1",    "6_1.U4(3).2_1"  ],
> [ "6_1.U4(3)",   "2.U4(3)",      "2.U4(3).2_2",    "6_1.U4(3).2_2"  ],
> [ "6_2.U4(3)",   "2.U4(3)",      "2.U4(3).2_1",    "6_2.U4(3).2_1"  ],
> [ "6_2.U4(3)",   "2.U4(3)",      "2.U4(3).2_3",    "6_2.U4(3).2_3"  ],
> [ "12_1.U4(3)",  "4.U4(3)",      "4.U4(3).2_1",    "12_1.U4(3).2_1" ],
> [ "12_2.U4(3)",  "4.U4(3)",      "4.U4(3).2_1",    "12_2.U4(3).2_1" ],
> [ "3.G2(3)",     "G2(3)",        "G2(3).2",        "3.G2(3).2"      ],
> [ "3.U3(8)",     "U3(8)",        "U3(8).2",        "3.U3(8).2"      ],
> [ "3.U3(8).3_1", "U3(8).3_1",    "U3(8).6",        "3.U3(8).6"      ],
> [ "3.J3",        "J3",           "J3.2",           "3.J3.2"         ],
> [ "3.U3(11)",    "U3(11)",       "U3(11).2",       "3.U3(11).2"     ],
> [ "3.McL",       "McL",          "McL.2",          "3.McL.2"        ],
> [ "3.07(3)",     "07(3)",        "07(3).2",        "3.07(3).2"      ],
> [ "6.07(3)",     "2.07(3)",      "2.07(3).2",      "6.07(3).2"      ],
> [ "3.U6(2)",     "U6(2)",        "U6(2).2",        "3.U6(2).2"      ],
> [ "6.U6(2)",     "2.U6(2)",      "2.U6(2).2",      "6.U6(2).2"      ],
> [ "3.Suz",       "Suz",          "Suz.2",          "3.Suz.2"        ],
> [ "6.Suz",       "2.Suz",        "2.Suz.2",        "6.Suz.2"        ],
> [ "3.ON",        "ON",           "ON.2",           "3.ON.2"         ],
> [ "3.Fi22",      "Fi22",         "Fi22.2",         "3.Fi22.2"       ],
> [ "6.Fi22",      "2.Fi22",       "2.Fi22.2",       "6.Fi22.2"       ],
> [ "3.2E6(2)",    "2E6(2)",       "2E6(2).2",       "3.2E6(2).2"    ],
> [ "6.2E6(2)",    "2.2E6(2)",     "2.2E6(2).2",     "6.2E6(2).2"    ],
> [ "3.F3+",       "F3+",          "F3+.2",          "3.F3+.2"        ],
> ];;

```

Note that the groups of the types $12_1.L_3(4).2_1$ and $12_2.L_3(4).2_1$ have central subgroups of order six, so we cannot choose G equal to $4_1.L_3(4)$ and $4_2.L_3(4)$, respectively, in these cases. See Section 4.4 for the construction of these tables.

Also in the following cases, $|A|$ and $|M|$ are coprime, we have $|M| = 3$ and $|A| = 2$. The group $M.G$ has a central subgroup of the type $2^2 \times 3$, and A acts on this group by inverting the elements in the subgroup of order 3 and by swapping two involutions in the Klein four group.

```

gap> Append( listMGA, [
> [ "(2^2x3).L3(4)", "2^2.L3(4)", "2^2.L3(4).2_2", "(2^2x3).L3(4).2_2" ],
> [ "(2^2x3).L3(4)", "2^2.L3(4)", "2^2.L3(4).2_3", "(2^2x3).L3(4).2_3" ],
> [ "(2^2x3).U6(2)", "2^2.U6(2)", "2^2.U6(2).2", "(2^2x3).U6(2).2" ],
> [ "(2^2x3).2E6(2)", "2^2.2E6(2)", "2^2.2E6(2).2", "(2^2x3).2E6(2).2" ],
> ] );

```

Additionally, there are a few cases where A has order two, and $G.A$ has a factor group of the type 2^2 , and a few cases where M has the type 2^2 and A is of order three and acts transitively on the involutions in M .

```
gap> Append( listMGA, [
> [ "3.A6.2_3",      "A6.2_3",      "A6.2^2",      "3.A6.2^2"      ],
> [ "3.L3(4).2_1",  "L3(4).2_1",  "L3(4).2^2",  "3.L3(4).2^2"  ],
> [ "3_1.U4(3).2_2", "U4(3).2_2", "U4(3).(2^2)_{122}",
>                                     "3_1.U4(3).(2^2)_{122}" ],
> [ "3_2.U4(3).2_3", "U4(3).2_3", "U4(3).(2^2)_{133}",
>                                     "3_2.U4(3).(2^2)_{133}" ],
> [ "3^2.U4(3).2_3'", "3_2.U4(3).2_3'", "3_2.U4(3).(2^2)_{133}",
>                                     "3^2.U4(3).(2^2)_{133}" ],
> [ "2^2.L3(4)",    "L3(4)",    "L3(4).3",    "2^2.L3(4).3" ],
> [ "(2^2x3).L3(4)", "3.L3(4)",  "3.L3(4).3",  "(2^2x3).L3(4).3" ],
> [ "2^2.L3(4).2_1", "L3(4).2_1", "L3(4).6",    "2^2.L3(4).6" ],
> [ "2^2.Sz(8)",     "Sz(8)",     "Sz(8).3",    "2^2.Sz(8).3" ],
> [ "2^2.U6(2)",     "U6(2)",     "U6(2).3",    "2^2.U6(2).3" ],
> [ "(2^2x3).U6(2)", "3.U6(2)",   "3.U6(2).3",  "(2^2x3).U6(2).3" ],
> [ "2^2.08+(2)",    "08+(2)",    "08+(2).3",   "2^2.08+(2).3" ],
> [ "2^2.08+(3)",    "08+(3)",    "08+(3).3",   "2^2.08+(3).3" ],
> [ "2^2.2E6(2)",    "2E6(2)",    "2E6(2).3",   "2^2.2E6(2).3" ],
> ] );
```

The constructions of the character tables of groups of the types $4_2.L_3(4).2_3$ and $12_2.L_3(4).2_3$ is described in Section 4.5, in these cases the GAP functions return several possible tables.

The construction of the various character table of groups of the types $4_1.L_3(4).2^2$ and $4_2.L_3(4).2^2$ are described in Section 6.7.

The following function takes the ordinary character tables of the groups $M.G$, G , and $G.A$, a string to be used as the `Identifier` value of the character table of $M.G.A$, and the character table of $M.G.A$ that is contained in the GAP Character Table Library; the function first computes the possible actions of $G.A$ on the classes of $M.G$, using the function `PossibleActionsForTypeMGA`, then computes the union of possible character tables for these actions, and then representatives up to permutation equivalence; if there is only one solution then the result table is compared with the library table.

```
gap> ConstructOrdinaryMGATable:= function( tblMG, tblG, tblGA, name, lib )
>   local acts, poss, trans;
>
>   acts:= PossibleActionsForTypeMGA( tblMG, tblG, tblGA );
>   poss:= Concatenation( List( acts, pi ->
>     PossibleCharacterTablesOfTypeMGA( tblMG, tblG, tblGA, pi,
>     name ) ) );
>   poss:= RepresentativesCharacterTables( poss );
>   if Length( poss ) = 1 then
>     # Compare the computed table with the library table.
>     if not IsCharacterTable( lib ) then
>       List( poss, x -> AutomorphismsOfTable( x.table ) );
>       Print( "#I no library table for ", name, "\n" );
>     else
>       trans:= TransformingPermutationsCharacterTables( poss[1].table,
>       lib );
>       if not IsRecord( trans ) then
>         Print( "#E computed table and library table for ", name,
>         " differ\n" );
```

```

>         fi;
>         # Compare the computed fusion with the stored one.
>         if OnTuples( poss[1].MGfusMGA, trans.columns )
>             <> GetFusionMap( tblMG, lib ) then
>                 Print( "#E computed and stored fusion for ", name,
>                     " differ\n" );
>         fi;
>         fi;
>     elif Length( poss ) = 0 then
>         Print( "#E no solution for ", name, "\n" );
>     else
>         Print( "#E ", Length( poss ), " possibilities for ", name, "\n" );
>         fi;
>     return poss;
> end;;

```

The following function takes the ordinary character tables of the groups $M.G$, $G.A$, and $M.G.A$, and tries to construct the p -modular character tables of $M.G.A$ from the p -modular character tables of the first two of these tables, for all prime divisors p of the order of $M.G.A$. Note that the tables of G are not needed in the construction, only the class fusions from $M.G$ to $M.G.A$ and from $M.G.A$ to $G.A$ must be stored.

```

gap> ConstructModularMGATables:= function( tblMG, tblGA, ordtblMGA )
>   local name, poss, p, modtblMG, modtblGA, modtblMGA, modlib, trans;
>
>   name:= Identifier( ordtblMGA );
>   poss:= [];
>   for p in Set( Factors( Size( ordtblMGA ) ) ) do
>     modtblMG := tblMG mod p;
>     modtblGA := tblGA mod p;
>     if ForAll( [ modtblMG, modtblGA ], IsCharacterTable ) then
>       modtblMGA:= BrauerTableOfTypeMGA( modtblMG, modtblGA, ordtblMGA );
>       Add( poss, modtblMGA );
>       modlib:= ordtblMGA mod p;
>       if IsCharacterTable( modlib ) then
>         trans:= TransformingPermutationsCharacterTables( modtblMGA.table,
>             modlib );
>         if not IsRecord( trans ) then
>           Print( "#E computed table and library table for ", name,
>               " mod ", p, " differ\n" );
>           fi;
>         else
>           AutomorphismsOfTable( modtblMGA.table );
>           Print( "#I no library table for ", name, " mod ", p, "\n" );
>           fi;
>         else
>           Print( "#I not all input tables for ", name, " mod ", p,
>               " available\n" );
>           fi;
>       od;
>     return poss;
>   end;;

```

Now we run the constructions for the cases in the list. Note that in order to avoid conflicts of the class fusions that arise in the construction with the class fusions that are already stored on the library

tables, we choose identifiers for the result tables that are different from the identifiers of the library tables.

```

gap> for input in listMGA do
>   tblMG := CharacterTable( input[1] );
>   tblG  := CharacterTable( input[2] );
>   tblGA := CharacterTable( input[3] );
>   name  := Concatenation( "new", input[4] );
>   lib   := CharacterTable( input[4] );
>   poss:= ConstructOrdinaryMGATable( tblMG, tblG, tblGA, name, lib );
>   if 1 <> Length( poss ) then
>     Print( "#I ", Length( poss ), " possibilities for ", name, "\n" );
>   elif lib = fail then
>     Print( "#I no library table for ", input[4], "\n" );
>   else
>     ConstructModularMGATables( tblMG, tblGA, lib );
>   fi;
> od;
#I not all input tables for 6.Suz.2 mod 13 available
#I not all input tables for 3.ON.2 mod 3 available
#I not all input tables for 3.2E6(2).2 mod 2 available
#I not all input tables for 3.2E6(2).2 mod 3 available
#I not all input tables for 3.2E6(2).2 mod 5 available
#I not all input tables for 3.2E6(2).2 mod 7 available
#I not all input tables for 3.2E6(2).2 mod 11 available
#I not all input tables for 3.2E6(2).2 mod 13 available
#I not all input tables for 3.2E6(2).2 mod 17 available
#I not all input tables for 3.2E6(2).2 mod 19 available
#I not all input tables for 6.2E6(2).2 mod 2 available
#I not all input tables for 6.2E6(2).2 mod 3 available
#I not all input tables for 6.2E6(2).2 mod 5 available
#I not all input tables for 6.2E6(2).2 mod 7 available
#I not all input tables for 6.2E6(2).2 mod 11 available
#I not all input tables for 6.2E6(2).2 mod 13 available
#I not all input tables for 6.2E6(2).2 mod 17 available
#I not all input tables for 6.2E6(2).2 mod 19 available
#I not all input tables for 3.F3+.2 mod 2 available
#I not all input tables for 3.F3+.2 mod 3 available
#I not all input tables for 3.F3+.2 mod 5 available
#I not all input tables for 3.F3+.2 mod 7 available
#I not all input tables for 3.F3+.2 mod 13 available
#I not all input tables for 3.F3+.2 mod 17 available
#I not all input tables for 3.F3+.2 mod 29 available
#I not all input tables for (2^2x3).2E6(2).2 mod 2 available
#I not all input tables for (2^2x3).2E6(2).2 mod 3 available
#I not all input tables for (2^2x3).2E6(2).2 mod 5 available
#I not all input tables for (2^2x3).2E6(2).2 mod 7 available
#I not all input tables for (2^2x3).2E6(2).2 mod 11 available
#I not all input tables for (2^2x3).2E6(2).2 mod 13 available
#I not all input tables for (2^2x3).2E6(2).2 mod 17 available
#I not all input tables for (2^2x3).2E6(2).2 mod 19 available
#I not all input tables for 3^2.U4(3).(2^2)_{133} mod 2 available
#I not all input tables for 3^2.U4(3).(2^2)_{133} mod 5 available
#I not all input tables for 3^2.U4(3).(2^2)_{133} mod 7 available
#I not all input tables for 2^2.O8+(3).3 mod 3 available

```

```

#I not all input tables for 2^2.08+(3).3 mod 5 available
#I not all input tables for 2^2.08+(3).3 mod 7 available
#I not all input tables for 2^2.08+(3).3 mod 13 available
#I not all input tables for 2^2.2E6(2).3 mod 2 available
#I not all input tables for 2^2.2E6(2).3 mod 3 available
#I not all input tables for 2^2.2E6(2).3 mod 5 available
#I not all input tables for 2^2.2E6(2).3 mod 7 available
#I not all input tables for 2^2.2E6(2).3 mod 11 available
#I not all input tables for 2^2.2E6(2).3 mod 13 available
#I not all input tables for 2^2.2E6(2).3 mod 17 available
#I not all input tables for 2^2.2E6(2).3 mod 19 available

```

We do not get any unexpected output, so the character tables in question are determined by the inputs.

Alternative constructions of the character tables of $3.A_6.2^2$, $3.L_3(4).2^2$, and $3_2.U_4(3).(2^2)_{133}$ can be found in Section 6.2.

4.4 More Atlas Tables of the Type $M.G.A$

In the following situations, we have $|A| = 2$, and $|M|$ is a multiple of 2. The result turns out to be unique up to isoclinism, see Section 3.1.

First, there are some cases where the centre of $M.G$ is a cyclic group of order four, and $|M| = 2$ holds.

```

gap> listMGA2:= [
> [ "4_1.L3(4)", "2.L3(4)", "2.L3(4).2_1", "4_1.L3(4).2_1" ],
> [ "4_1.L3(4)", "2.L3(4)", "2.L3(4).2_2", "4_1.L3(4).2_2" ],
> [ "4_2.L3(4)", "2.L3(4)", "2.L3(4).2_1", "4_2.L3(4).2_1" ],
> [ "4.M22", "2.M22", "2.M22.2", "4.M22.2" ],
> [ "4.U4(3)", "2.U4(3)", "2.U4(3).2_2", "4.U4(3).2_2" ],
> [ "4.U4(3)", "2.U4(3)", "2.U4(3).2_3", "4.U4(3).2_3" ],
> ];;

```

Note that the groups $4_1.L_3(4).2_3$ and $4_2.L_3(4).2_2$ and their isoclinic variants have centres of order four, so they do not appear here. The construction of the character table of $4_2.L_3(4).2_3$ is more involved, it is described in Section 4.5.

Also in the following cases, we have $|M| = 2$, but the situation is different because $M.G$ has a central subgroup of the type 2^2 containing a unique subgroup of order 2 that is central in $M.G.A$.

```

gap> Append( listMGA2, [
> [ "2^2.L3(4)", "2.L3(4)", "2.L3(4).2_2", "2^2.L3(4).2_2" ],
> [ "2^2.L3(4)", "2.L3(4)", "2.L3(4).2_3", "2^2.L3(4).2_3" ],
> [ "2^2.L3(4).2_1", "2.L3(4).2_1", "2.L3(4).(2^2)_{123}", "2^2.L3(4).2^2" ],
> [ "2^2.08+(2)", "2.08+(2)", "2.08+(2).2", "2^2.08+(2).2" ],
> [ "2^2.U6(2)", "2.U6(2)", "2.U6(2).2", "2^2.U6(2).2" ],
> [ "2^2.2E6(2)", "2.2E6(2)", "2.2E6(2).2", "2^2.2E6(2).2" ],
> ] );

```

Next there are two constructions for $G = 6.L_3(4)$, with $|M| = 12$ and $|A| = 2$. Note that the groups $12_1.L_3(4).2_1$ and $12_2.L_3(4).2_1$ have central subgroups of the order six, so we cannot use the factor groups $4_1.L_3(4).2_1$ and $4_2.L_3(4).2_1$, respectively, for the constructions.

```

gap> Append( listMGA2, [
> [ "12_1.L3(4)", "6.L3(4)", "6.L3(4).2_1", "12_1.L3(4).2_1" ],
> [ "12_2.L3(4)", "6.L3(4)", "6.L3(4).2_1", "12_2.L3(4).2_1" ],
> ] );

```

Next there are alternative constructions for tables which have been constructed in Section 4.3. There we had viewed the groups of the structure 12.S.2, for a simple group S , as 3.G.2 with $G = 4.S$. Here we view these groups as 2.G.2 with $G = 6.S$, which means that we do not prescribe the 4.S.2 type factor group. So it is not surprising that we get more than one solution, and that the computation of the 2-power map of 12.S.2 is more involved. Note that the construction of the character table of $12_2.L_3(4).2_3$ is more involved, it is described in Section 4.5.

```

gap> Append( listMGA2, [
> [ "12.M22", "6.M22", "6.M22.2", "12.M22.2" ],
> [ "12_1.L3(4)", "6.L3(4)", "6.L3(4).2_2", "12_1.L3(4).2_2" ],
> [ "12_1.U4(3)", "6_1.U4(3)", "6_1.U4(3).2_2", "12_1.U4(3).2_2" ],
> [ "12_2.U4(3)", "6_2.U4(3)", "6_2.U4(3).2_3", "12_2.U4(3).2_3" ],
> ] );

```

Finally, there are alternative constructions for the cases where the group $M.G$ has a central subgroup of the type $2^2 \times 3$, and A acts on this group by inverting the elements in the subgroup of order 3 and by swapping two involutions in the Klein four group.

```

gap> Append( listMGA2, [
> [ "(2^2x3).L3(4)", "6.L3(4)", "6.L3(4).2_2", "(2^2x3).L3(4).2_2" ],
> [ "(2^2x3).L3(4)", "6.L3(4)", "6.L3(4).2_3", "(2^2x3).L3(4).2_3" ],
> [ "(2^2x3).U6(2)", "6.U6(2)", "6.U6(2).2", "(2^2x3).U6(2).2" ],
> [ "(2^2x3).2E6(2)", "6.2E6(2)", "6.2E6(2).2", "(2^2x3).2E6(2).2" ],
> ] );

```

Now we run the constructions for the cases in the list.

```

gap> for input in listMGA2 do
>   tblMG := CharacterTable( input[1] );
>   tblG  := CharacterTable( input[2] );
>   tblGA := CharacterTable( input[3] );
>   name  := Concatenation( "new", input[4] );
>   lib   := CharacterTable( input[4] );
>   poss := ConstructOrdinaryMGATable( tblMG, tblG, tblGA, name, lib );
>   if Length( poss ) = 2 then
>     iso := CharacterTableIsoclinic( poss[1].table );
>     if IsRecord( TransformingPermutationsCharacterTables( poss[2].table,
>       iso ) ) then
>       Unbind( poss[2] );
>     fi;
>   elif Length( poss ) = 1 then
>     Print( "#I unique up to permutation equivalence: ", name, "\n" );
>   fi;
>   if 1 <> Length( poss ) then
>     Print( "#I ", Length( poss ), " possibilities for ", name, "\n" );
>   elif lib = fail then
>     Print( "#I no library table for ", input[4], "\n" );
>   else
>     ConstructModularMGATables( tblMG, tblGA, lib );
>   fi;
end;

```

```

> od;
#E 2 possibilities for new4_1.L3(4).2_1
#E 2 possibilities for new4_1.L3(4).2_2
#E 2 possibilities for new4_2.L3(4).2_1
#E 2 possibilities for new4.M22.2
#E 2 possibilities for new4.U4(3).2_2
#E 2 possibilities for new4.U4(3).2_3
#I unique up to permutation equivalence: new2^2.L3(4).2_2
#I unique up to permutation equivalence: new2^2.L3(4).2_3
#I unique up to permutation equivalence: new2^2.L3(4).2^2
#I unique up to permutation equivalence: new2^2.08+(2).2
#I unique up to permutation equivalence: new2^2.U6(2).2
#I unique up to permutation equivalence: new2^2.2E6(2).2
#I not all input tables for 2^2.2E6(2).2 mod 2 available
#I not all input tables for 2^2.2E6(2).2 mod 3 available
#I not all input tables for 2^2.2E6(2).2 mod 5 available
#I not all input tables for 2^2.2E6(2).2 mod 7 available
#E 2 possibilities for new12_1.L3(4).2_1
#E 2 possibilities for new12_2.L3(4).2_1
#E 2 possibilities for new12.M22.2
#E 2 possibilities for new12_1.L3(4).2_2
#E 2 possibilities for new12_1.U4(3).2_2
#E 2 possibilities for new12_2.U4(3).2_3
#I unique up to permutation equivalence: new(2^2x3).L3(4).2_2
#I unique up to permutation equivalence: new(2^2x3).L3(4).2_3
#I unique up to permutation equivalence: new(2^2x3).U6(2).2
#I unique up to permutation equivalence: new(2^2x3).2E6(2).2
#I not all input tables for (2^2x3).2E6(2).2 mod 2 available
#I not all input tables for (2^2x3).2E6(2).2 mod 3 available
#I not all input tables for (2^2x3).2E6(2).2 mod 5 available
#I not all input tables for (2^2x3).2E6(2).2 mod 7 available
#I not all input tables for (2^2x3).2E6(2).2 mod 11 available
#I not all input tables for (2^2x3).2E6(2).2 mod 13 available
#I not all input tables for (2^2x3).2E6(2).2 mod 17 available
#I not all input tables for (2^2x3).2E6(2).2 mod 19 available

```

Again, we do not get any unexpected output, so the character tables in question are determined up to isoclinism by the inputs.

4.5 The Character Tables of $4_2.L_3(4).2_3$ and $12_2.L_3(4).2_3$

In the construction of the character table of $M.G.A = 4_2.L_3(4).2_3$ from the tables of $M.G = 4_2.L_3(4)$ and $G.A = 2.L_3(4).2_3$, the action of A on the classes of $M.G$ is uniquely determined, but we get four possible character tables.

```

gap> tblMG := CharacterTable( "4_2.L3(4)" );;
gap> tblG := CharacterTable( "2.L3(4)" );;
gap> tblGA := CharacterTable( "2.L3(4).2_3" );;
gap> name := "new4_2.L3(4).2_3";;
gap> lib := CharacterTable( "4_2.L3(4).2_3" );;
gap> poss := ConstructOrdinaryMGATable( tblMG, tblG, tblGA, name, lib );
#E 4 possibilities for new4_2.L3(4).2_3
[ rec( MGfusMGA := [ 1, 2, 3, 2, 4, 5, 6, 7, 8, 7, 9, 10, 11, 10, 12, 12, 13,
14, 15, 14, 16, 17, 18, 17, 19, 20, 21, 22, 19, 22, 21, 20 ],

```

```

      table := CharacterTable( "new4_2.L3(4).2_3" ) ),
rec( MGFusMGA := [ 1, 2, 3, 2, 4, 5, 6, 7, 8, 7, 9, 10, 11, 10, 12, 12, 13,
      14, 15, 14, 16, 17, 18, 17, 19, 20, 21, 22, 19, 22, 21, 20 ],
      table := CharacterTable( "new4_2.L3(4).2_3" ) ),
rec( MGFusMGA := [ 1, 2, 3, 2, 4, 5, 6, 7, 8, 7, 9, 10, 11, 10, 12, 12, 13,
      14, 15, 14, 16, 17, 18, 17, 19, 20, 21, 22, 19, 22, 21, 20 ],
      table := CharacterTable( "new4_2.L3(4).2_3" ) ),
rec( MGFusMGA := [ 1, 2, 3, 2, 4, 5, 6, 7, 8, 7, 9, 10, 11, 10, 12, 12, 13,
      14, 15, 14, 16, 17, 18, 17, 19, 20, 21, 22, 19, 22, 21, 20 ],
      table := CharacterTable( "new4_2.L3(4).2_3" ) ) ]

```

The centre of $4_2.L_3(4)$ is inverted by the action of the outer automorphism, so the existence of *two* possible tables can be expected because two isoclinic groups of the type $4_2.L_3(4).2_3$ exist, see Section 2.5.

Indeed the result consists of two pairs of isoclinic tables, so we have to decide which pair of tables belongs to the groups of the type $4_2.L_3(4).2_3$.

```

gap> IsRecord( TransformingPermutationsCharacterTables( poss[1].table,
>
      CharacterTableIsoclinic( poss[4].table ) ) );
true
gap> IsRecord( TransformingPermutationsCharacterTables( poss[2].table,
>
      CharacterTableIsoclinic( poss[3].table ) ) );
true

```

The possible tables differ only w.r.t. the 2-power map and perhaps the element orders. The ATLAS prints the table of the split extension of $M.G$, this table is one of the first two possibilities.

```

gap> List( poss, x -> PowerMap( x.table, 2 ) );
[ [ 1, 3, 1, 1, 3, 6, 8, 6, 4, 4, 4, 5, 16, 18, 16, 13, 15, 13, 19, 21, 19,
  21, 1, 1, 6, 6, 9, 9, 11, 11, 16, 16, 13, 13 ],
  [ 1, 3, 1, 1, 3, 6, 8, 6, 4, 4, 4, 5, 16, 18, 16, 13, 15, 13, 19, 21, 19,
  21, 1, 1, 6, 6, 11, 11, 9, 9, 16, 16, 13, 13 ],
  [ 1, 3, 1, 1, 3, 6, 8, 6, 4, 4, 4, 5, 16, 18, 16, 13, 15, 13, 19, 21, 19,
  21, 3, 3, 8, 8, 9, 9, 11, 11, 18, 18, 15, 15 ],
  [ 1, 3, 1, 1, 3, 6, 8, 6, 4, 4, 4, 5, 16, 18, 16, 13, 15, 13, 19, 21, 19,
  21, 3, 3, 8, 8, 11, 11, 9, 9, 18, 18, 15, 15 ] ]

```

The 2-power map is not determined by the irreducible characters (and by the 2-power map of the factor group $2.L_3(4).2_3$). We determine this map using the embedding of $4_2.L_3(4).2_3$ into $4.U_4(3).2_3$. Note that $L_3(4).2_3$ is a maximal subgroup of $U_4(3).2_3$ (see [CCN⁺85, p. 52]), and that the subgroup $L_3(4)$ of $U_4(3)$ lifts to $4_2.L_3(4)$ in $4.U_4(3)$ because no embedding of $L_3(4)$, $2.L_3(4)$, or $4_1.L_3(4)$ into $4.U_4(3)$ is possible.

```

gap> PossiblePowerMaps( poss[1].table, 2 );
[ [ 1, 3, 1, 1, 3, 6, 8, 6, 4, 4, 4, 5, 16, 18, 16, 13, 15, 13, 19, 21, 19,
  21, 1, 1, 6, 6, 11, 11, 9, 9, 16, 16, 13, 13 ],
  [ 1, 3, 1, 1, 3, 6, 8, 6, 4, 4, 4, 5, 16, 18, 16, 13, 15, 13, 19, 21, 19,
  21, 1, 1, 6, 6, 9, 9, 11, 11, 16, 16, 13, 13 ] ]
gap> t:= CharacterTable( "4.U4(3)" );
gap> List( [ "L3(4)", "2.L3(4)", "4_1.L3(4)", "4_2.L3(4)" ], name ->
>
      Length( PossibleClassFusions( CharacterTable( name ), t ) ) );
[ 0, 0, 0, 4 ]

```

So the split extension $4_2.L_3(4).2_3$ of $4_2.L_3(4)$ is a subgroup of the split extension $4.U_4(3).2_3$ of $4.U_4(3)$, and only one of the two possible tables of $4_2.L_3(4).2_3$ admits a class fusion into the ATLAS table of $4.U_3(4).2_3$; the construction of the latter table is shown in Section 4.3.

```

gap> t2:= CharacterTable( "4.U4(3).2_3" );;
gap> List( poss, x -> Length( PossibleClassFusions( x.table, t2 ) ) );
[ 0, 16, 0, 0 ]

```

I do not know a character theoretic argument that would disprove the existence of a group whose character table is the other candidate (or its isoclinic variant). For example, the table passes the tests from Section 4.12.

(It is straightforward to compute all extensions of $4_2.L_3(4)$ by an automorphism of order two. The extensions with 34 conjugacy classes belong to the second candidate and its isoclinic variant.)

The correct table is the one that is contained in the GAP Character Table Library.

```

gap> IsRecord( TransformingPermutationsCharacterTables( poss[2].table,
>
> lib ) );
true
gap> ConstructModularMGATables( tblMG, tblGA, lib );;

```

In the construction of the character table of $12_2.L_3(4).2_3$, the same ambiguity arises. We resolve it using the fact that $4_2.L_3(4).2_3$ occurs as a factor group, modulo the unique normal subgroup of order three.

```

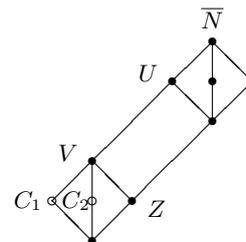
gap> tblMG := CharacterTable( "12_2.L3(4)" );;
gap> tblG := CharacterTable( "6.L3(4)" );;
gap> tblGA := CharacterTable( "6.L3(4).2_3" );;
gap> name := "new12_2.L3(4).2_3";;
gap> lib := CharacterTable( "12_2.L3(4).2_3" );;
gap> poss := ConstructOrdinaryMGATable( tblMG, tblG, tblGA, name, lib );;
#E 4 possibilities for new12_2.L3(4).2_3
gap> Length( poss );
4
gap> nsg:= ClassPositionsOfNormalSubgroups( poss[1].table );
[ [ 1 ], [ 1, 5 ], [ 1, 7 ], [ 1, 4 .. 7 ], [ 1, 3 .. 7 ], [ 1 .. 7 ],
  [ 1 .. 50 ], [ 1 .. 62 ] ]
gap> List( nsg, x -> Sum( SizesConjugacyClasses( poss[1].table ){ x } ) );
[ 1, 3, 2, 4, 6, 12, 241920, 483840 ]
gap> factlib:= CharacterTable( "4_2.L3(4).2_3" );;
gap> List( poss, x -> IsRecord( TransformingPermutationsCharacterTables(
>
> x.table / [ 1, 5 ], factlib ) ) );
[ false, true, false, false ]
gap> IsRecord( TransformingPermutationsCharacterTables( poss[2].table,
>
> lib ) );
true
gap> ConstructModularMGATables( tblMG, tblGA, lib );;

```

4.6 The Character Table of $(2^2 \times F_4(2)) : 2 < B$ (March 2003)

The sporadic simple group B contains a maximal subgroup \bar{N} of type $(2^2 \times F_4(2)) : 2$, which is the normalizer of a 2C element \bar{x} in B (see [CCN⁺85, p. 217]).

We will see below that the normal Klein four group V in \bar{N} contains two 2A elements in B . The 2A centralizer in B , a group of the structure $2.^2E_6(2).2$, contains maximal subgroups of the type $2^2 \times F_4(2)$. So the two 2A type subgroups C_1, C_2 in V are conjugate in \bar{N} , and $Z = \langle x \rangle$ is the centre of \bar{N} .



We start with computing the class fusion of the $2^2 \times F_4(2)$ type subgroup U of \overline{N} into B ; in order to speed this up, we first compute the class fusion of the $F_4(2)$ subgroup of U into B (which is unique), and use it and the stored embedding into U for prescribing an approximation of the desired class fusion. Additionally, we prescribe (without loss of generality) that the *first* involution class in V is mapped to the class 2C of B .

```
gap> f42:= CharacterTable( "F4(2)" );;
gap> v4:= CharacterTable( "2^2" );;
gap> dp:= v4 * f42;
CharacterTable( "V4xF4(2)" )
gap> b:= CharacterTable( "B" );;
gap> f42fusb:= PossibleClassFusions( f42, b );;
gap> Length( f42fusb );
1
gap> f42fusdp:= GetFusionMap( f42, dp );;
gap> comp:= CompositionMaps( f42fusb[1], InverseMap( f42fusdp ) );
[ 1, 3, 3, 3, 5, 6, 6, 7, 9, 9, 9, 9, 14, 14, 13, 13, 10, 14, 14, 12, 14, 17,
  15, 18, 22, 22, 22, 22, 26, 26, 22, 22, 27, 27, 28, 31, 31, 39, 39, 36, 36,
  33, 33, 39, 39, 35, 41, 42, 47, 47, 49, 49, 49, 58, 58, 56, 56, 66, 66, 66,
  66, 58, 58, 66, 66, 69, 69, 60, 72, 72, 75, 79, 79, 81, 81, 85, 86, 83, 83,
  91, 91, 94, 94, 104, 104, 109, 109, 116, 116, 114, 114, 132, 132, 140, 140 ]
gap> v4fusdp:= GetFusionMap( v4, dp );
[ 1, 96 .. 286 ]
gap> comp[ v4fusdp[2] ]:= 4;;
gap> dpfusb:= PossibleClassFusions( dp, b, rec( fusionmap:= comp ) );;
gap> Length( dpfusb );
4
gap> Set( List( dpfusb, x -> x{ v4fusdp } ) );
[ [ 1, 4, 2, 2 ] ]
```

As announced above, we see that V contains two 2A involutions.

Set $G = U/Z$, $M.G = U$, and $G.A = \overline{N}/Z$. The latter group is the direct product of $F_4(2).2$ and a cyclic group of order 2. Next we compute the class fusion from G into $G.A$.

```
gap> tblG:= dp / v4fusdp{ [ 1, 2 ] };;
gap> tblMG:= dp;;
gap> c2:= CharacterTable( "Cyclic", 2 );;
gap> tblGA:= c2 * CharacterTable( "F4(2).2" );;
CharacterTable( "C2xF4(2).2" )
gap> GfusGA:= PossibleClassFusions( tblG, tblGA );;
gap> Length( GfusGA );
4
gap> Length( RepresentativesFusions( tblG, GfusGA, tblGA ) );
1
```

In principle, we have to be careful which of these equivalent maps we choose, since the underlying symmetries may be broken in the central extension $M.G \rightarrow G$, for which we choose the default factor fusion.

However, in this situation the fusion G into $G.A$ is unique already up to table automorphisms of the table of $G.A$, so we are free to choose one map.

```
gap> Length( RepresentativesFusions( Group( () ), GfusGA, tblGA ) );
1
gap> StoreFusion( tblG, GfusGA[1], tblGA );
```

The tables involved determine the character table of $M.G.A \cong \overline{N}$ uniquely.

```
gap> elms:= PossibleActionsForTypeMGA( tblMG, tblG, tblGA );;
gap> Length( elms );
1
gap> poss:= PossibleCharacterTablesOfTypeMGA( tblMG, tblG, tblGA, elms[1],
>      "(2^2xF4(2)):2" );;
gap> Length( poss );
1
gap> tblMGA:= poss[1].table;;
```

Finally, we compare the table we constructed with the one that is contained in the GAP Character Table Library.

```
gap> IsRecord( TransformingPermutationsCharacterTables( tblMGA,
>      CharacterTable( "(2^2xF4(2)):2" ) ) );
true
```

4.7 The Character Table of $2.(S_3 \times Fi_{22}.2) \leq 2.B$ (March 2003)

The sporadic simple group B contains a maximal subgroup \overline{M} of type $S_3 \times Fi_{22}.2$. In order to compute the character table of its preimage M in the Schur cover $2.B$, we first analyse the structure of M and then describe the construction of the character table from known character tables.

Let Z denote the centre of $2.B$. We start with $\overline{M} = M/Z$. Its class fusion into B is uniquely determined by the character tables.

```
gap> s3:= CharacterTable( "Dihedral", 6 );;
gap> fi22:= CharacterTable( "Fi22.2" );;
gap> tblMbar:= s3 * fi22;;
gap> b:= CharacterTable( "B" );;
gap> Mbarfusb:= PossibleClassFusions( tblMbar, b );;
gap> Length( Mbarfusb );
1
```

The subgroup of type Fi_{22} lifts to the double cover $2.Fi_{22}$ (that is, a group that is *not* a direct product $2 \times Fi_{22}$) in $2.B$ since $2.B$ admits no class fusion from Fi_{22} .

```
gap> 2b:= CharacterTable( "2.B" );;
gap> PossibleClassFusions( CharacterTable( "Fi22" ), 2b );
[ ]
```

So the preimage of $Fi_{22}.2$ is one of the two nonisomorphic but isoclinic groups of type $2.Fi_{22}.2$, and we have to decide which one really occurs. For that, we consider the subgroup of type $3 \times Fi_{22}.2$ in B , which is a 3A centralizer in B . Its preimage has the structure $3 \times 2.Fi_{22}.2$ because the preimage of the central group of order 3 is a cyclic group of order 6 and thus contains a normal complement of the $2.Fi_{22}$ type subgroup. And a class fusion into $2.B$ is possible only from the direct product containing the $2.Fi_{22}.2$ group that is printed in the ATLAS.

```
gap> c3:= CharacterTable( "Cyclic", 3 );;
gap> 2fi22:= CharacterTable( "2.Fi22.2" );;
gap> PossibleClassFusions( c3 * CharacterTableIsoclinic( 2fi22 ), 2b );
[ ]
```

Next we note that the involutions in the normal subgroup \overline{S} of type S_3 in \overline{M} lift to involutions in $2.B$.

```

gap> s3inMbar:= GetFusionMap( s3, tblMbar );
[ 1, 113 .. 225 ]
gap> s3inb:= Mbarfusb[1]{ s3inMbar };
[ 1, 6, 2 ]
gap> 2bfusb:= GetFusionMap( 2b, b );;
gap> 2s3in2B:= InverseMap( 2bfusb ){ s3inb };
[ [ 1, 2 ], [ 8, 9 ], 3 ]
gap> CompositionMaps( OrdersClassRepresentatives( 2b ), 2s3in2B );
[ [ 1, 2 ], [ 3, 6 ], 2 ]

```

Thus the preimage S of \bar{S} contains elements of order 6 but no elements of order 4, which implies that S is a direct product $2 \times S_3$.

The two complements C_1, C_2 of Z in S are normal in the preimage N of $\bar{N} = S_3 \times Fi_{22}$, which is thus of type $S_3 \times 2.Fi_{22}$. However, they are conjugate under the action of $2.Fi_{22}.2$, as no class fusion from $S_3 \times 2.Fi_{22}.2$ into $2.B$ is possible.

```

gap> PossibleClassFusions( s3 * 2fi222, 2b );
[ ]

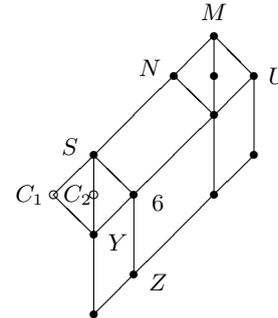
```

(More specifically, the classes of element order 36 in $2.Fi_{22}.2$ have centralizer orders 36 and 72, so their centralizer orders in $S_3 \times 2.Fi_{22}.2$ are 216 and 432; but the centralizers of order 36 elements in $2.B$ have centralizer order at most 216.)

Now let us see how the character table of M can be constructed.

Let Y denote the normal subgroup of order 3 in M , and U its centralizer in M , which has index 2 in M . Then the character table of M is determined by the tables of $M/Y, U, U/Y \cong 2.Fi_{22}.2$, and the action of M on the classes of U .

As for M/Y , consider the normal subgroup $N = N_M(C_1)$ of index 2 in M . In particular, S/Y is central in N/Y but not in M/Y , so the character table of M/Y is determined by the tables of $M/(YZ), N/Y \cong 2 \times 2.Fi_{22}, N/(YZ) \cong 2 \times Fi_{22}$, and the action of M/Y on the classes of N/Y . Thus we proceed in two steps, starting with the computation of the character table of M/Y , for which we choose the name according to the structure $2^2.Fi_{22}.2$.



```

gap> c2:= CharacterTable( "Cyclic", 2 );;
gap> 2fi22:= CharacterTable( "2.Fi22" );;
gap> tblNmodY:= c2 * 2fi22;;
gap> centre:= GetFusionMap( 2fi22, tblNmodY ){
>           ClassPositionsOfCentre( 2fi22 ) };
[ 1, 2 ]
gap> tblNmod6:= tblNmodY / centre;;
gap> tblMmod6:= c2 * fi22;;
gap> fus:= PossibleClassFusions( tblNmod6, tblMmod6 );;
gap> Length( fus );
1
gap> StoreFusion( tblNmod6, fus[1], tblMmod6 );
gap> elms:= PossibleActionsForTypeMGA( tblNmodY, tblNmod6, tblMmod6 );;
gap> Length( elms );
1
gap> poss:= PossibleCharacterTablesOfTypeMGA( tblNmodY, tblNmod6, tblMmod6,

```

```

>          elms[1], "2^2.Fi22.2" );;
gap> Length( poss );
1
gap> tblMmodY:= poss[1].table;
CharacterTable( "2^2.Fi22.2" )

```

So we found a unique solution for the character table of M/Y . Now we compute the table of M . For that, we have to specify the class fusion of U/Y into M/Y ; it is unique up to table automorphisms of M/Y .

```

gap> tblU:= c3 * 2fi222;;
gap> tblUmodY:= tblU / GetFusionMap( c3, tblU );;
gap> fus:= PossibleClassFusions( tblUmodY, tblMmodY );;
gap> Length( RepresentativesFusions( Group( ) ), fus, tblMmodY );
1
gap> StoreFusion( tblUmodY, fus[1], tblMmodY );
gap> elms:= PossibleActionsForTypeMGA( tblU, tblUmodY, tblMmodY );;
gap> Length( elms );
1
gap> poss:= PossibleCharacterTablesOfTypeMGA( tblU, tblUmodY, tblMmodY,
>          elms[1], "(S3x2.Fi22).2" );;
gap> Length( poss );
1
gap> tblM:= poss[1].table;
CharacterTable( "(S3x2.Fi22).2" )
gap> mfus2b:= PossibleClassFusions( tblM, 2b );;
gap> Length( RepresentativesFusions( tblM, mfus2b, 2b ) );
1

```

We did not construct M as a central extension of \overline{M} , so we verify that the tables fit together; note that this way we get also the class fusion from M onto \overline{M} .

```

gap> Irr( tblM / ClassPositionsOfCentre( tblM ) ) = Irr( tblMbar );
true

```

Finally, we compare the table we constructed with the one that is contained in the GAP Character Table Library.

```

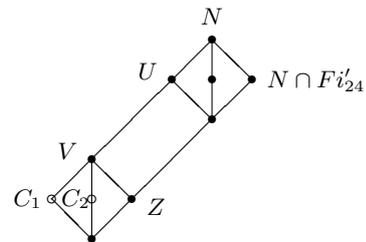
gap> IsRecord( TransformingPermutationsCharacterTables( tblM,
>          CharacterTable( "(S3x2.Fi22).2" ) ) );
true

```

4.8 The Character Table of $(2 \times 2.Fi_{22}) : 2 < Fi_{24}$ (November 2008)

The automorphism group Fi_{24} of the sporadic simple group Fi'_{24} contains a maximal subgroup N of the type $(2 \times 2.Fi_{22}) : 2$, whose intersection with Fi'_{24} is $2.Fi_{22}.2$ (see [CCN⁺85, p. 207]).

The normal Klein four group V in N contains two $2C$ elements in Fi_{24} , because the $2C$ centralizer in Fi_{24} , a group of the structure $2 \times Fi_{23}$, contains maximal subgroups of the type $2 \times 2.Fi_{22}$, and so the two $2C$ type subgroups C_1, C_2 in V are conjugate in N , and $Z = Z(N)$ is the centre of $N \cap Fi'_{24}$.



With $U = C_N(C_1)$, a group of the type $2 \times 2.Fi_{22}$, we set $G = U/Z$, $M.G = U$, and $G.A = N/Z$. The latter group is the direct product of $Fi_{22}.2$ and a cyclic group of order 2.

This is exactly the situation of the construction of the character table of the group that is called $2^2.Fi_{22}.2$ in Section 4.7, where this group occurs as “ M/Y ”. Since the character table is uniquely determined by the input data, it is the table we are interested in here.

So all we have to do is to compute the class fusion from this table into that of Fi_{24} .

```
gap> fi24:= CharacterTable( "Fi24" );;
gap> t:= CharacterTable( "2^2.Fi22.2" );;
gap> fus:= PossibleClassFusions( t, fi24 );;
gap> Length( fus );
4
gap> Length( RepresentativesFusions( t, fus, fi24 ) );
1
```

(It should be noted that we did not need the character table of the $2.Fi_{22}.2$ type subgroup of N in the above construction, only the tables of $2.Fi_{22}$ and $Fi_{22}.2$ were used.)

The fact that the character table of a factor of a subgroup of $2.B$ occurs as the character table of a subgroup of Fi_{24} is not a coincidence. In fact, the groups $3.Fi_{24}$ and $2.B$ are subgroups of the Monster group M , and the subgroup $U = 2.(S_3 \times Fi_{22}.2)$ of $2.B$ normalizes an element of order three. The full normalizer of this element in M is $3.Fi_{24}$, which means that we have established U as a (maximal) subgroup of $3.Fi_{24}$. Note that we have constructed the character table of U in Section 4.7.

Let us compute the class fusion of U into $3.Fi_{24}$.

```
gap> t:= CharacterTable( "(S3x2.Fi22).2" );;
gap> 3fi24:= CharacterTable( "3.Fi24" );;
gap> fus:= PossibleClassFusions( t, 3fi24 );;
gap> Length( fus );
16
gap> Length( RepresentativesFusions( t, fus, 3fi24 ) );
1
gap> GetFusionMap( t, 3fi24 ) in fus;
true
```

Moreover, U turns out to be the full normalizer of a 6A element in M ,

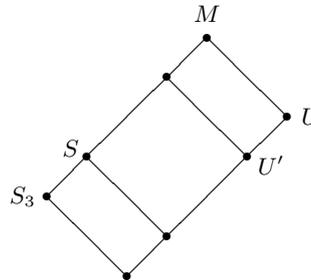
```
gap> m:= CharacterTable( "M" );;
gap> tfusm:= PossibleClassFusions( t, m );;
gap> Length( tfusm );
4
gap> Length( RepresentativesFusions( t, tfusm, m ) );
1
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
> x -> Sum( SizesConjugacyClasses( t ){ x } ) = 6 );
[ [ 1, 2, 142, 143 ] ]
gap> Set( List( tfusm, x -> x{ nsg[1] } ) );
[ [ 1, 2, 4, 13 ] ]
gap> OrdersClassRepresentatives( t ){ nsg[1] };
[ 1, 2, 3, 6 ]
gap> PowerMap( m, -1 )[13];
13
gap> Size( t ) = 2 * SizesCentralizers( m )[13];
true
```

(Thus U is also the full normalizer of an element of order six in $2.B$ and in $3.Fi_{24}$.)

4.9 The Character Table of $S_3 \times 2.U_4(3).2_2 \leq 2.Fi_{22}$ (September 2002)

The sporadic simple Fischer group Fi_{22} contains a maximal subgroup \overline{M} of type $S_3 \times U_4(3).2_2$ (see [CCN⁺85, p. 163]). We claim that the preimage M of \overline{M} in the central extension $2.Fi_{22}$ has the structure $S_3 \times 2.U_4(3).2_2$, where the factor of type $2.U_4(3).2_2$ is the one printed in the ATLAS.

For that, we first note that the normal subgroup \overline{S} of type S_3 in \overline{M} lifts to a group S which has the structure $2 \times S_3$. This follows from the fact that all involutions in Fi_{22} lift to involutions in $2.Fi_{22}$ or, equivalently, the central involution in $2.Fi_{22}$ is not a square.



```
gap> 2Fi22:= CharacterTable( "2.Fi22" );;
gap> ClassPositionsOfCentre( 2Fi22 );
[ 1, 2 ]
gap> 2 in PowerMap( 2Fi22, 2 );
false
```

Second, the normal subgroup $\overline{U} \cong U_4(3).2_2$ of Fi_{22} lifts to a nonsplit extension U in $2.Fi_{22}$, since $2.Fi_{22}$ contains no $U_4(3)$ type subgroup. Furthermore, U is the $2.U_4(3).2_2$ type group printed in the ATLAS because the isoclinic variant does not admit a class fusion into $2.Fi_{22}$.

```
gap> PossibleClassFusions( CharacterTable( "U4(3)" ), 2Fi22 );
[ ]
gap> tblU:= CharacterTable( "2.U4(3).2_2" );;
gap> iso:= CharacterTableIsoclinic( tblU );
CharacterTable( "Isoclinic(2.U4(3).2_2)" )
gap> PossibleClassFusions( iso, 2Fi22 );
[ ]
```

Now there are just two possibilities. Either the two S_3 type subgroups in S are normal in M (and thus M is the direct product of any such S_3 with the preimage of the $U_4(3).2_2$ type subgroup), or they are conjugate in M .

Suppose we are in the latter situation, let z be a generator of the centre of $2.Fi_{22}$, and let τ, σ be an involution and an order three element respectively, in one of the S_3 type subgroups.

Each element $g \in U \setminus U'$ conjugates τ to an involution in the other S_3 type subgroup of S , so $g^{-1}\tau g = \tau\sigma^i z$ for some $i \in \{0, 1, 2\}$. Furthermore, it is possible to choose g as an involution.

```
gap> derpos:= ClassPositionsOfDerivedSubgroup( tblU );;
gap> outer:= Difference( [ 1 .. NrConjugacyClasses( tblU ) ], derpos );;
gap> 2 in OrdersClassRepresentatives( tblU ){ outer };
true
```

With this choice, $(g\tau)^2 = \tau\sigma^i z\tau = \sigma^{-i} z$ holds, which means that $(g\tau)^3$ squares to z . As we have seen above, this is impossible, hence M is a direct product, as claimed.

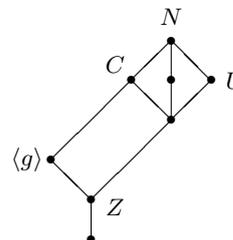
The class fusion of M into $2.Fi_{22}$ is determined by the character tables, up to table automorphisms.

```
gap> tblM:= CharacterTable( "Dihedral", 6 ) * tblU;;
gap> fus:= PossibleClassFusions( tblM, 2Fi22 );;
gap> Length( RepresentativesFusions( tblM, fus, 2Fi22 ) );
1
gap> IsRecord( TransformingPermutationsCharacterTables( tblM,
> CharacterTable( "2.Fi22M8" ) ) );
true
```

4.10 The Character Table of $4.HS.2 \leq HN.2$ (May 2002)

The maximal subgroup U of type $2.HS.2$ in the sporadic simple group HN extends to a group N of structure $4.HS.2$ in the automorphism group $HN.2$ of HN (see [CCN⁺85, p. 166]).

N is the normalizer of a $4D$ element $g \in HN.2 \setminus HN$. The centralizer C of g is of type $4.HS$, which is the central product of $2.HS$ and the cyclic group $\langle g \rangle$ of order 4. We have $Z = Z(N) = \langle g^2 \rangle$. Since $U/Z \cong HS.2$ is a complement of $\langle g \rangle/Z$ in N/Z , the factor group N/Z is a direct product of $HS.2$ and a cyclic group of order 2.



Thus N has the structure $2.G.2$, the normal subgroup $2.G$ being C , the factor group $G.2$ being $2 \times HS.2$, and G being $2 \times HS$. Each element in $N \setminus C$ inverts g , so N acts fixed point freely on the faithful irreducible characters of C . Hence we can use `PossibleCharacterTablesOfTypeMGA` for constructing the character table of N from the tables of C and N/Z and the action of N on the classes of C .

We start with the table of the central product C . It can be viewed as an isoclinic table of the direct product of $2.HS$ and a cyclic group of order 2, see 2.4.

```
gap> c2:= CharacterTable( "Cyclic", 2 );;
gap> tblC:= CharacterTableIsoclinic( CharacterTable( "2.HS" ) * c2 );;
```

The table of G is given as that of the factor group by the unique normal subgroup of C that consists of two conjugacy classes.

```
gap> ord2:= Filtered( ClassPositionsOfNormalSubgroups( tblC ),
> x -> Length( x ) = 2 );
[ [ 1, 3 ] ]
gap> tblCbar:= tblC / ord2[1];;
```

Finally, we construct the table of the extension $G.2$ and the class fusion of G into this table (which is uniquely determined by the character tables).

```
gap> tblNbar:= CharacterTable( "HS.2" ) * c2;;
gap> fus:= PossibleClassFusions( tblCbar, tblNbar );
[ [ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20,
21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 29, 30, 31, 32, 33, 34, 35, 36,
35, 36, 37, 38, 39, 40, 41, 42, 41, 42 ] ]
gap> StoreFusion( tblCbar, fus[1], tblNbar );
```

Now we compute the table automorphisms of the table of C that are compatible with the extension N ; we get two solutions.

```
gap> elms:= PossibleActionsForTypeMGA( tblC, tblCbar, tblNbar );
[ [ [ 1 ], [ 2, 4 ], [ 3 ], [ 5 ], [ 6, 8 ], [ 7 ], [ 9 ], [ 10 ], [ 11 ],
[ 12, 14 ], [ 13 ], [ 15 ], [ 16, 18 ], [ 17 ], [ 19 ], [ 20 ], [ 21 ],
[ 22 ], [ 23 ], [ 24, 26 ], [ 25 ], [ 27 ], [ 28, 30 ], [ 29 ], [ 31 ],
[ 32, 34 ], [ 33 ], [ 35 ], [ 36, 38 ], [ 37 ], [ 39 ], [ 40, 42 ],
[ 41 ], [ 43 ], [ 44, 46 ], [ 45 ], [ 47 ], [ 48, 50 ], [ 49 ],
[ 51, 53 ], [ 52, 54 ], [ 55 ], [ 56, 58 ], [ 57 ], [ 59 ], [ 60 ],
[ 61, 65 ], [ 62, 68 ], [ 63, 67 ], [ 64, 66 ], [ 69 ], [ 70, 72 ],
[ 71 ], [ 73 ], [ 74, 76 ], [ 75 ], [ 77, 81 ], [ 78, 84 ], [ 79, 83 ],
[ 80, 82 ] ],
[ [ 1 ], [ 2, 4 ], [ 3 ], [ 5 ], [ 6, 8 ], [ 7 ], [ 9 ], [ 10 ], [ 11 ],
```

```

[ 12, 14 ], [ 13 ], [ 15, 17 ], [ 16 ], [ 18 ], [ 19 ], [ 20 ], [ 21 ],
[ 22 ], [ 23 ], [ 24, 26 ], [ 25 ], [ 27 ], [ 28, 30 ], [ 29 ], [ 31 ],
[ 32, 34 ], [ 33 ], [ 35, 37 ], [ 36 ], [ 38 ], [ 39 ], [ 40, 42 ],
[ 41 ], [ 43 ], [ 44, 46 ], [ 45 ], [ 47, 49 ], [ 48 ], [ 50 ],
[ 51, 53 ], [ 52, 54 ], [ 55 ], [ 56, 58 ], [ 57 ], [ 59 ], [ 60 ],
[ 61, 65 ], [ 62, 68 ], [ 63, 67 ], [ 64, 66 ], [ 69, 71 ], [ 70 ],
[ 72 ], [ 73 ], [ 74, 76 ], [ 75 ], [ 77, 83 ], [ 78, 82 ], [ 79, 81 ],
[ 80, 84 ] ] ]

```

We compute the possible character tables arising from these two actions.

```

gap> poss:= List( elms, pi -> PossibleCharacterTablesOfTypeMGA(
>          tblC, tblCbar, tblNbar, pi, "4.HS.2" ) );;
gap> List( poss, Length );
[ 0, 2 ]

```

So one of the two table automorphisms turned out to be impossible; the reason is that the corresponding “character table” would not admit a 2-power map. (Alternatively, we could exclude this action on C by the fact that it is not compatible with the action of $2.HS.2$ on its subgroup $2.HS$, which occurs here as the restriction of the action of N on C to that of U on $C \cap U$.)

The other table automorphism leads to two possible character tables. This is not surprising since N contains a subgroup of type $2.HS.2$, and the above setup does not determine which of the two isoclinism types of this group occurs. Let us look at the possible class fusions from these tables into that of $HN.2$:

```

gap> result:= poss[2];;
gap> hn2:= CharacterTable( "HN.2" );;
gap> possfus:= List( result, r -> PossibleClassFusions( r.table, hn2 ) );;
gap> List( possfus, Length );
[ 32, 0 ]
gap> RepresentativesFusions( result[1].table, possfus[1], hn2 );
[ [ 1, 46, 2, 2, 47, 3, 7, 45, 4, 58, 13, 6, 46, 47, 6, 47, 7, 48, 10, 62,
    20, 9, 63, 21, 12, 64, 24, 27, 49, 50, 13, 59, 14, 16, 70, 30, 18, 53,
    52, 17, 54, 20, 65, 22, 36, 56, 26, 76, 39, 77, 28, 59, 58, 31, 78, 41,
    34, 62, 35, 65, 2, 45, 3, 45, 6, 48, 7, 47, 17, 54, 13, 49, 13, 50, 14,
    50, 18, 53, 18, 52, 21, 56, 25, 57, 27, 59, 30, 60, 44, 72, 34, 66, 35,
    66, 41, 71 ] ]

```

Only one of the candidates admits an embedding, and the class fusion is unique up to table automorphisms. So we are done.

Finally, we compare the table we have constructed with the one that is contained in the GAP Character Table Library.

```

gap> libtbl:= CharacterTable( "4.HS.2" );;
gap> IsRecord( TransformingPermutationsCharacterTables( result[1].table,
>          libtbl ) );
true

```

(The following paragraphs have been added in May 2006.)

The Brauer tables of $N = 2.G.2$ can be constructed as in Section 4.3. Note that the Brauer tables of $C = 2.G$ and of $N/Z = G.2$ are automatically available because the ordinary tables constructed above arose as a direct product and as an isoclinic table of a direct product, and the GAP Character Table Library contains the Brauer tables of the direct factors involved.

```

gap> StoreFusion( tblC, result[1].MGfusMGA, result[1].table );
gap> ForAll( Set( Factors( Size( result[1].table ) ) ),
>          p -> IsRecord( TransformingPermutationsCharacterTables(
>                          BrauerTableOfTypeMGA( tblC mod p, tblNbar mod p,
>                          result[1].table ).table, libtbl mod p ) ) );
true

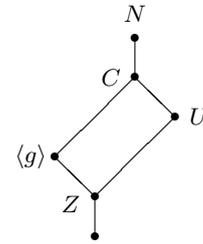
```

Here it is advantageous that the Brauer table of $C/Z = G$ is not needed in the construction, since GAP does not know how to compute the p -modular table of the ordinary table of G constructed above. Of course we have $G \cong 2 \times HS$, and the p -modular table of HS is known, but in the construction of the table of G as a factor of the table of $2.G$, the information is missing that the nonsolvable simple direct factor of $2.G$ corresponds to the library table of HS .

4.11 The Character Tables of $4.A_6.2_3$, $12.A_6.2_3$, and $4.L_2(25).2_3$

For the “broken box” cases in the ATLAS (see [CCN⁺85, p. xxiv]), the character tables can be constructed with the *M.G.A* construction method from Section 3.1.

The group $N = 4.A_6.2_3$ (see [CCN⁺85, p. 5]) can be described as an upward extension of the normal subgroup $C \cong 4.A_6$ —which is a central product of $U = 2.A_6$ and a cyclic group $\langle g \rangle$ of order 4—by a cyclic group of order 2, such that the factor group of N by the central subgroup $Z = \langle g^2 \rangle$ of order 2 is isomorphic to a subdirect product \bar{N} of $M_{10} = A_6.2_3$ and a cyclic group of order 4 and that N acts nontrivially on its normal subgroup $\langle g \rangle$.



Thus N has the structure $2.G.2$, with $2.G = C$ and $G.2 = \bar{N}$. These two groups are isoclinic variants of $2 \times 2.A_6$ and of $2 \times M_{10}$, respectively. Each element in $N \setminus C$ inverts g , so it acts fixed point freely on the faithful irreducible characters of C . Hence we can use `PossibleCharacterTablesOfTypeMGA` for constructing the character table of N from the tables of C and N/Z and the action of N on the classes of C .

```

gap> c2:= CharacterTable( "Cyclic", 2 );;
gap> 2a6:= CharacterTable( "2.A6" );;
gap> tblC:= CharacterTableIsoclinic( 2a6 * c2 );;
gap> ord2:= Filtered( ClassPositionsOfNormalSubgroups( tblC ),
>                    x -> Length( x ) = 2 );
[ [ 1, 3 ] ]
gap> tblG:= tblC / ord2[1];;
gap> tblNbar:= CharacterTableIsoclinic( CharacterTable( "A6.2_3" ) * c2 );;
gap> fus:= PossibleClassFusions( tblG, tblNbar );
[ [ 1, 2, 3, 4, 5, 6, 5, 6, 7, 8, 9, 10, 9, 10 ] ]
gap> StoreFusion( tblG, fus[1], tblNbar );
gap> elms:= PossibleActionsForTypeMGA( tblC, tblG, tblNbar );
[ [ [ 1 ], [ 2 ], [ 3 ], [ 4 ], [ 5 ], [ 6 ], [ 7, 11 ], [ 8, 12 ],
    [ 9, 13 ], [ 10, 14 ], [ 15, 17 ], [ 16, 18 ], [ 19, 23 ], [ 20, 24 ],
    [ 21, 25 ], [ 22, 26 ] ],
  [ [ 1 ], [ 2, 4 ], [ 3 ], [ 5 ], [ 6 ], [ 7, 11 ], [ 8, 14 ], [ 9, 13 ],
    [ 10, 12 ], [ 15 ], [ 16, 18 ], [ 17 ], [ 19, 23 ], [ 20, 26 ],
    [ 21, 25 ], [ 22, 24 ] ],
  [ [ 1 ], [ 2, 4 ], [ 3 ], [ 5 ], [ 6 ], [ 7, 11 ], [ 8, 14 ], [ 9, 13 ],
    [ 10, 12 ], [ 15, 17 ], [ 16 ], [ 18 ], [ 19, 23 ], [ 20, 26 ],
    [ 21, 25 ], [ 22, 24 ] ] ]
gap> poss:= List( elms, pi -> PossibleCharacterTablesOfTypeMGA(

```

```

>          tblC, tblG, tblNbar, pi, "4.A6.2_3" ) );
[ [ ], [ ],
  [
    rec( MGfusMGA := [ 1, 2, 3, 2, 4, 5, 6, 7, 8, 9, 6, 9, 8, 7, 10, 11, 10,
                      12, 13, 14, 15, 16, 13, 16, 15, 14 ],
        table := CharacterTable( "4.A6.2_3" ) ) ] ]

```

So we get a unique solution. It coincides with the character table of $4.A_6.2_3$ that is stored in the GAP Character Table Library.

```

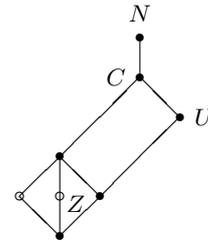
gap> IsRecord( TransformingPermutationsCharacterTables( poss[3][1].table,
>          CharacterTable( "4.A6.2_3" ) ) );
true

```

Note that the first two candidates for the action lead to tables that do not admit a 2-power map. In fact the 2-power map of the character table of $4.A_6.2_3$ is not uniquely determined by the matrix of character values. However, the 2-power map is unique up to automorphisms of this matrix; the function `PossibleCharacterTablesOfTypeMGA` takes this into account, and returns only representatives, in this case one table.

The ATLAS states in [CCN⁺85, Section 6.7] that there is a group of the structure $2^2.A_6.2_3$ that is isoclinic with $4.A_6.2_3$. We construct also the character table of the $2^2.A_6.2_3$ type group with the *M.G.A* construction method from Section 3.1.

The group $N = 2^2.A_6.2_3$ can be described as an upward extension of the normal subgroup $C \cong 2 \times 2.A_6$ by a cyclic group of order 2, such that the factor group of N by the central subgroup Z of order 2 that is contained in $U = C' \cong 2.A_6$ is isomorphic to a subdirect product \bar{N} of $M_{10} = A_6.2_3$ and a cyclic group of order 4 and that N acts nontrivially on the centre of C , which is a Klein four group.



Thus N has the structure $2.G.2$, with $2.G = C$ and $G.2 = \bar{N}$. These latter group is an isoclinic variant of $2 \times M_{10}$, as in the construction of $4.A_6.2_3$. Each element in $N \setminus C$ swaps the two involutions in $Z(C) \setminus Z$, so it acts fixed point freely on those irreducible characters of C whose kernels do not contain Z . Hence we can use `PossibleCharacterTablesOfTypeMGA` for constructing the character table of N from the tables of C and N/Z and the action of N on the classes of C .

```

gap> tblC:= 2a6 * c2;;
gap> z:= GetFusionMap( 2a6, tblC ){ ClassPositionsOfCentre( 2a6 ) };
[ 1, 3 ]
gap> tblG:= tblC / z;;
gap> tblNbar:= CharacterTableIsoclinic( CharacterTable( "A6.2_3" ) * c2 );;
gap> fus:= PossibleClassFusions( tblG, tblNbar );
[ [ 1, 2, 3, 4, 5, 6, 5, 6, 7, 8, 9, 10, 9, 10 ] ]
gap> StoreFusion( tblG, fus[1], tblNbar );
gap> elms:= PossibleActionsForTypeMGA( tblC, tblG, tblNbar );
[ [ [ 1 ], [ 2 ], [ 3 ], [ 4 ], [ 5 ], [ 6 ], [ 7, 11 ], [ 8, 12 ],
    [ 9, 13 ], [ 10, 14 ], [ 15, 17 ], [ 16, 18 ], [ 19, 23 ], [ 20, 24 ],
    [ 21, 25 ], [ 22, 26 ] ],
  [ [ 1 ], [ 2, 4 ], [ 3 ], [ 5 ], [ 6 ], [ 7, 11 ], [ 8, 14 ], [ 9, 13 ],
    [ 10, 12 ], [ 15 ], [ 16, 18 ], [ 17 ], [ 19, 23 ], [ 20, 26 ],
    [ 21, 25 ], [ 22, 24 ] ],
  [ [ 1 ], [ 2, 4 ], [ 3 ], [ 5 ], [ 6 ], [ 7, 11 ], [ 8, 14 ], [ 9, 13 ],
    [ 10, 12 ], [ 15, 17 ], [ 16 ], [ 18 ], [ 19, 23 ], [ 20, 26 ],
    [ 21, 25 ], [ 22, 24 ] ] ]
gap> poss:= List( elms, pi -> PossibleCharacterTablesOfTypeMGA(

```

```

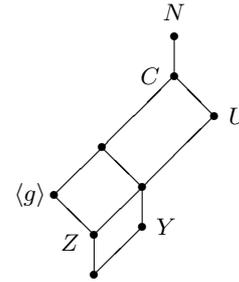
>          tblC, tblG, tblNbar, pi, "2^2.A6.2_3" ) );
[ [ ], [ ],
  [
    rec( MGfusMGA := [ 1, 2, 3, 2, 4, 5, 6, 7, 8, 9, 6, 9, 8, 7, 10, 11, 10,
                      12, 13, 14, 15, 16, 13, 16, 15, 14 ],
        table := CharacterTable( "2^2.A6.2_3" ) ) ] ]

```

So we get a unique solution.

The group $N = 12.A_6.2_3$ (see [CCN⁺85, p. 5]) can be described as an upward extension of the normal subgroup $C \cong 12.A_6$ –which is a central product of $U = 6.A_6$ and a cyclic group $\langle g \rangle$ of order 4– by a cyclic group of order 2, such that the factor group of N by the central subgroup $Z = \langle g^2 \rangle$ of order 2 is isomorphic to a subdirect product \bar{N} of $3.M_{10} = 3.A_6.2_3$ and a cyclic group of order 4 and that N acts nontrivially on its normal subgroup $\langle g \rangle$.

Note that N has a central subgroup Y , say, of order 3, so the situation here differs from that for groups of the type $12.G.2$ with G one of $L_3(4)$, $U_4(3)$, where the action on the normal subgroup of order three is nontrivial.



Thus N has the structure $2.G.2$, with $2.G = C$ and $G.2 = \bar{N}$. These two groups are isoclinic variants of $2 \times 6.A_6$ and of $2 \times 3.M_{10}$, respectively. Each element in $N \setminus C$ inverts g , so it acts fixed point freely on the faithful irreducible characters of C . Hence we can use `PossibleCharacterTablesOfTypeMGA` for constructing the character table of N from the tables of C and N/Z and the action of N on the classes of C .

```

gap> c2:= CharacterTable( "Cyclic", 2 );;
gap> tblC:= CharacterTableIsoclinic( CharacterTable( "6.A6" ) * c2 );;
gap> ord2:= Filtered( ClassPositionsOfNormalSubgroups( tblC ),
>                   x -> Length( x ) = 2 );
[ [ 1, 7 ] ]
gap> tblG:= tblC / ord2[1];;
gap> tblNbar:= CharacterTableIsoclinic( CharacterTable( "3.A6.2_3" ) * c2 );;
gap> fus:= PossibleClassFusions( tblG, tblNbar );
[ [ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 13, 14, 15, 16, 17, 18,
    19, 20, 21, 22, 23, 24, 25, 26, 21, 22, 23, 24, 25, 26 ],
  [ 1, 2, 5, 6, 3, 4, 7, 8, 11, 12, 9, 10, 13, 14, 13, 14, 15, 16, 19, 20,
    17, 18, 21, 22, 25, 26, 23, 24, 21, 22, 25, 26, 23, 24 ] ]
gap> rep:= RepresentativesFusions( Group( () ), fus, tblNbar );
[ [ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 13, 14, 15, 16, 17, 18,
    19, 20, 21, 22, 23, 24, 25, 26, 21, 22, 23, 24, 25, 26 ] ]
gap> StoreFusion( tblG, rep[1], tblNbar );
gap> elms:= PossibleActionsForTypeMGA( tblC, tblG, tblNbar );
[ [ [ 1 ], [ 2 ], [ 3 ], [ 4 ], [ 5 ], [ 6 ], [ 7 ], [ 8 ], [ 9 ], [ 10 ],
    [ 11 ], [ 12 ], [ 13 ], [ 14 ], [ 15 ], [ 16 ], [ 17 ], [ 18 ],
    [ 19, 23 ], [ 20, 24 ], [ 21, 25 ], [ 22, 26 ], [ 27, 33 ], [ 28, 34 ],
    [ 29, 35 ], [ 30, 36 ], [ 31, 37 ], [ 32, 38 ], [ 39, 51 ], [ 40, 52 ],
    [ 41, 53 ], [ 42, 54 ], [ 43, 55 ], [ 44, 56 ], [ 45, 57 ], [ 46, 58 ],
    [ 47, 59 ], [ 48, 60 ], [ 49, 61 ], [ 50, 62 ] ],
  [ [ 1 ], [ 2, 8 ], [ 3 ], [ 4, 10 ], [ 5 ], [ 6, 12 ], [ 7 ], [ 9 ],
    [ 11 ], [ 13 ], [ 14 ], [ 15 ], [ 16 ], [ 17 ], [ 18 ], [ 19, 23 ],
    [ 20, 26 ], [ 21, 25 ], [ 22, 24 ], [ 27 ], [ 28, 34 ], [ 29 ],
    [ 30, 36 ], [ 31 ], [ 32, 38 ], [ 33 ], [ 35 ], [ 37 ], [ 39, 51 ],
    [ 40, 58 ], [ 41, 53 ], [ 42, 60 ], [ 43, 55 ], [ 44, 62 ], [ 45, 57 ],

```

```

    [ 46, 52 ], [ 47, 59 ], [ 48, 54 ], [ 49, 61 ], [ 50, 56 ] ],
  [ [ 1 ], [ 2, 8 ], [ 3 ], [ 4, 10 ], [ 5 ], [ 6, 12 ], [ 7 ], [ 9 ],
    [ 11 ], [ 13 ], [ 14 ], [ 15 ], [ 16 ], [ 17 ], [ 18 ], [ 19, 23 ],
    [ 20, 26 ], [ 21, 25 ], [ 22, 24 ], [ 27, 33 ], [ 28 ], [ 29, 35 ],
    [ 30 ], [ 31, 37 ], [ 32 ], [ 34 ], [ 36 ], [ 38 ], [ 39, 51 ],
    [ 40, 58 ], [ 41, 53 ], [ 42, 60 ], [ 43, 55 ], [ 44, 62 ], [ 45, 57 ],
    [ 46, 52 ], [ 47, 59 ], [ 48, 54 ], [ 49, 61 ], [ 50, 56 ] ] ]
gap> poss:= List( elms, pi -> PossibleCharacterTablesOfTypeMGA(
>
>   tblC, tblG, tblNbar, pi, "12.A6.2_3" ) );
[ [ ], [ ],
  [
    rec( MGfusMGA := [ 1, 2, 3, 4, 5, 6, 7, 2, 8, 4, 9, 6, 10, 11, 12, 13, 14,
      15, 16, 17, 18, 19, 16, 19, 18, 17, 20, 21, 22, 23, 24, 25, 20,
      26, 22, 27, 24, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39,
      40, 29, 36, 31, 38, 33, 40, 35, 30, 37, 32, 39, 34 ],
      table := CharacterTable( "12.A6.2_3" ) ) ] ]

```

So we get again a unique solution. It coincides with the character table that is stored in the GAP Character Table Library.

```

gap> IsRecord( TransformingPermutationsCharacterTables( poss[3][1].table,
>
>   CharacterTable( "12.A6.2_3" ) ) );
true

```

The construction of the character table of $4.L_2(25).2_3$ is analogous to that of the table of $4.A_6.2_3$. We get a unique table that coincides with the table in the GAP library.

```

gap> c2:= CharacterTable( "Cyclic", 2 );;
gap> tblC:= CharacterTableIsoclinic( CharacterTable( "2.L2(25)" ) * c2 );;
gap> ord2:= Filtered( ClassPositionsOfNormalSubgroups( tblC ),
>
>   x -> Length( x ) = 2 );
[ [ 1, 3 ] ]
gap> tblG:= tblC / ord2[1];;
gap> tblNbar:= CharacterTableIsoclinic( CharacterTable( "L2(25).2_3" ) * c2 );;
gap> fus:= PossibleClassFusions( tblG, tblNbar );
[ [ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 9, 10, 11, 12, 13, 14, 13, 14, 15, 16, 15,
  16, 17, 18, 17, 18, 19, 20, 19, 20 ],
  [ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 9, 10, 11, 12, 13, 14, 13, 14, 17, 18, 17,
  18, 19, 20, 19, 20, 15, 16, 15, 16 ],
  [ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 9, 10, 11, 12, 13, 14, 13, 14, 19, 20, 19,
  20, 15, 16, 15, 16, 17, 18, 17, 18 ] ]
gap> rep:= RepresentativesFusions( Group( ) ), fus, tblNbar );
[ [ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 13, 14, 15, 16, 15,
  16, 17, 18, 17, 18, 19, 20, 19, 20 ] ]
gap> StoreFusion( tblG, rep[1], tblNbar );
gap> elms:= PossibleActionsForTypeMGA( tblC, tblG, tblNbar );
[ [ [ 1 ], [ 2 ], [ 3 ], [ 4 ], [ 5 ], [ 6 ], [ 7 ], [ 8 ], [ 9 ], [ 10 ],
  [ 11, 13 ], [ 12, 14 ], [ 15, 19 ], [ 16, 20 ], [ 17, 21 ], [ 18, 22 ],
  [ 23, 25 ], [ 24, 26 ], [ 27, 33 ], [ 28, 34 ], [ 29, 31 ], [ 30, 32 ],
  [ 35, 39 ], [ 36, 40 ], [ 37, 41 ], [ 38, 42 ], [ 43, 47 ], [ 44, 48 ],
  [ 45, 49 ], [ 46, 50 ], [ 51, 55 ], [ 52, 56 ], [ 53, 57 ], [ 54, 58 ] ] ],
  [ [ 1 ], [ 2, 4 ], [ 3 ], [ 5 ], [ 6 ], [ 7 ], [ 8, 10 ], [ 9 ],
  [ 11 ], [ 12, 14 ], [ 13 ], [ 15, 19 ], [ 16, 22 ], [ 17, 21 ],
  [ 18, 20 ], [ 23, 25 ], [ 24 ], [ 26 ], [ 27, 31 ], [ 28, 34 ],
  [ 29, 33 ], [ 30, 32 ], [ 35, 39 ], [ 36, 42 ], [ 37, 41 ], [ 38, 40 ],

```

```

      [ 43, 47 ], [ 44, 50 ], [ 45, 49 ], [ 46, 48 ], [ 51, 55 ], [ 52, 58 ],
      [ 53, 57 ], [ 54, 56 ] ],
    [ [ 1 ], [ 2, 4 ], [ 3 ], [ 5 ], [ 6 ], [ 7 ], [ 8, 10 ], [ 9 ],
      [ 11, 13 ], [ 12 ], [ 14 ], [ 15, 19 ], [ 16, 22 ], [ 17, 21 ],
      [ 18, 20 ], [ 23, 25 ], [ 24 ], [ 26 ], [ 27, 33 ], [ 28, 32 ],
      [ 29, 31 ], [ 30, 34 ], [ 35, 39 ], [ 36, 42 ], [ 37, 41 ], [ 38, 40 ],
      [ 43, 47 ], [ 44, 50 ], [ 45, 49 ], [ 46, 48 ], [ 51, 55 ], [ 52, 58 ],
      [ 53, 57 ], [ 54, 56 ] ] ]
gap> poss:= List( elms, pi -> PossibleCharacterTablesOfTypeMGA(
>
>      tblC, tblG, tblNbar, pi, "4.L2(25).2_3" ) );
[ [ ], [ ],
  [
    rec( MGfusMGA := [ 1, 2, 3, 2, 4, 5, 6, 7, 8, 7, 9, 10, 9, 11, 12, 13, 14,
      15, 12, 15, 14, 13, 16, 17, 16, 18, 19, 20, 21, 22, 21, 20, 19,
      22, 23, 24, 25, 26, 23, 26, 25, 24, 27, 28, 29, 30, 27, 30, 29,
      28, 31, 32, 33, 34, 31, 34, 33, 32 ],
      table := CharacterTable( "4.L2(25).2_3" ) ) ] ]
gap> IsRecord( TransformingPermutationsCharacterTables( poss[3][1].table,
>
>      CharacterTable( "4.L2(25).2_3" ) ) );
true

```

4.12 Pseudo Character Tables of the Type $M.G.A$ (May 2004)

With the construction method for character tables of groups of the type $M.G.A$, one can construct tables that have many properties of character tables but that are not character tables of groups, cf. [Gag86]. For example, the group $3.A_6.2_3$ has a *central* subgroup of order 3, so it is not of the type $M.G.A$ with fixed-point free action on the faithful characters of $M.G$.

However, if we apply the “ $M.G.A$ construction” to the groups $M.G = 3.A_6$, $G = A_6$, and $G.A = A_6.2_3$ then we get a (in this case unique) result.

```

gap> tblMG := CharacterTable( "3.A6" );;
gap> tblG := CharacterTable( "A6" );;
gap> tblGA := CharacterTable( "A6.2_3" );;
gap> elms:= PossibleActionsForTypeMGA( tblMG, tblG, tblGA );
[ [ [ 1 ], [ 2, 3 ], [ 4 ], [ 5, 6 ], [ 7, 8 ], [ 9 ], [ 10, 11 ],
  [ 12, 15 ], [ 13, 17 ], [ 14, 16 ] ] ]
gap> poss:= PossibleCharacterTablesOfTypeMGA(
>
>      tblMG, tblG, tblGA, elms[1], "pseudo" );
[ rec( MGfusMGA := [ 1, 2, 2, 3, 4, 4, 5, 5, 6, 7, 7, 8, 9, 10, 8, 10, 9 ],
  table := CharacterTable( "pseudo" ) ) ]

```

Such a table automatically satisfies the orthogonality relations, and the tensor product of two “irreducible characters” of which at least one is a row from $G.A$ decomposes into a sum of the “irreducible characters”, where the coefficients are nonnegative integers.

In this example, any tensor product decomposes with nonnegative integral coefficients, n -th symmetrizations of “irreducible characters” decompose, for $n \leq 5$, and the “class multiplication coefficients” are nonnegative integers.

```

gap> pseudo:= poss[1].table;
CharacterTable( "pseudo" )
gap> Display( pseudo );
pseudo

```

```

      2 4 3 4 3 . 3 2 . . . 2 3 3
      3 3 3 1 1 2 1 1 1 1 1 . . .
      5 1 1 . . . . . 1 1 1 . . .

      1a 3a 2a 6a 3b 4a 12a 5a 15a 15b 4b 8a 8b
2P 1a 3a 1a 3a 3b 2a 6a 5a 15a 15b 2a 4a 4a
3P 1a 1a 2a 2a 1a 4a 4a 5a 5a 5a 4b 8a 8b
5P 1a 3a 2a 6a 3b 4a 12a 1a 3a 3a 4b 8b 8a

X.1 1 1 1 1 1 1 1 1 1 1 1 1 1
X.2 1 1 1 1 1 1 1 1 1 1 -1 -1 -1
X.3 10 10 2 2 1 -2 -2 . . . . .
X.4 16 16 . . -2 . . 1 1 1 . . .
X.5 9 9 1 1 . 1 1 -1 -1 -1 1 -1 -1
X.6 9 9 1 1 . 1 1 -1 -1 -1 -1 1 1
X.7 10 10 -2 -2 1 . . . . . B -B
X.8 10 10 -2 -2 1 . . . . . -B B
X.9 6 -3 -2 1 . 2 -1 1 A /A . . .
X.10 6 -3 -2 1 . 2 -1 1 /A A . . .
X.11 12 -6 4 -2 . . . 2 -1 -1 . . .
X.12 18 -9 2 -1 . 2 -1 -2 1 1 . . .
X.13 30 -15 -2 1 . -2 1 . . . . .

A = -E(15)-E(15)^2-E(15)^4-E(15)^8
  = (-1-Sqrt(-15))/2 = -1-b15
B = E(8)+E(8)^3
  = Sqrt(-2) = i2
gap> IsInternallyConsistent( pseudo );
true
gap> irr:= Irr( pseudo );;
gap> test:= Concatenation( List( [ 2 .. 5 ],
> n -> Symmetrizations( pseudo, irr, n ) ) );;
gap> Append( test, Set( Tensored( irr, irr ) ) );
gap> fail in Decomposition( irr, test, "nonnegative" );
false
gap> if ForAny( Tuples( [ 1 .. NrConjugacyClasses( pseudo ) ], 3 ),
> t -> not ClassMultiplicationCoefficient( pseudo, t[1], t[2], t[3] )
> in NonnegativeIntegers ) then
> Error( "contradiction" );
> fi;

```

I do not know a character-theoretic argument for showing that this table is *not* the character table of a group, but we can use the following group-theoretic argument. Suppose that the group G , say, has the above character table. Then G has a unique composition series with factors of the orders 3, 360, and 2, respectively. Let N denote the normal subgroup of order 3 in G . The factor group $F = G/N$ is an automorphic extension of A_6 , and according to [CCN⁺85, p. 4] it is isomorphic with $M_{10} = A_6.2_3$ and has Sylow 3 normalizers of the structure $3^2 : Q_8$. Since the Sylow 3 subgroup of G is a self-centralizing nonabelian group of order 3^3 and of exponent 3, the Sylow 3 normalizers in G have the structure $3_+^{1+2} : Q_8$, but the Q_8 type subgroups of $\text{Aut}(3_+^{1+2})$ act trivially on the centre of 3_+^{1+2} , contrary to the situation in the above table.

In general, this construction need not produce tables for which all symmetrizations of irreducible characters decompose properly. For example, applying `PossibleCharacterTablesOfTypeMGA` to the case $M.G = 3.L_3(4)$ and $G.A = L_3(4).2_1$ does not yield a table because the function suppresses tables that do not admit p -th power maps, for prime divisors p of the order of $M.G.A$, and in this case no

compatible 2-power map exists.

```

gap> tblMG := CharacterTable( "3.L3(4)" );;
gap> tblG := CharacterTable( "L3(4)" );;
gap> tblGA := CharacterTable( "L3(4).2_1" );;
gap> elms:= PossibleActionsForTypeMGA( tblMG, tblG, tblGA );
[ [ [ 1 ], [ 2, 3 ], [ 4 ], [ 5, 6 ], [ 7 ], [ 8 ], [ 9, 10 ], [ 11 ],
    [ 12, 13 ], [ 14 ], [ 15, 16 ], [ 17, 20 ], [ 18, 22 ], [ 19, 21 ],
    [ 23, 26 ], [ 24, 28 ], [ 25, 27 ] ] ]
gap> PossibleCharacterTablesOfTypeMGA( tblMG, tblG, tblGA, elms[1], "?" );
[ ]

```

Also, it may happen that already `PossibleActionsForTypeMGA` returns an empty list. Examples are $M.G = 3_1.U_4(3)$, $G.A = U_4(3).2_2$ and $M.G = 3_2.U_4(3)$, $G.A = U_4(3).2_3$.

```

gap> tblG := CharacterTable( "U4(3)" );;
gap> tblMG := CharacterTable( "3_1.U4(3)" );;
gap> tblGA := CharacterTable( "U4(3).2_2" );;
gap> PossibleActionsForTypeMGA( tblMG, tblG, tblGA );
[ ]
gap> tblMG:= CharacterTable( "3_2.U4(3)" );;
gap> tblGA:= CharacterTable( "U4(3).2_3" );;
gap> PossibleActionsForTypeMGA( tblMG, tblG, tblGA );
[ ]

```

4.13 Some Extra-ordinary p -Modular Tables of the Type $M.G.A$ (September 2005)

For a group $M.G.A$ in the sense of Section 3.1 such that **not** all ordinary irreducible characters χ have the property that M is contained in the kernel of χ or χ is induced from $M.G$, it may happen that there are primes p such that all irreducible p -modular characters have this property. This happens if and only if the preimages in $M.G.A$ of each p -regular conjugacy class in $G.A \setminus G$ form one conjugacy class.

The following function can be used to decide whether this situation applies to a character table in the GAP Character Table Library; here we assume that for the library table of a group with the structure $M.G.A$, the class fusions from $M.G$ and to $G.A$ are stored.

```

gap> FindExtraordinaryCase:= function( tblMGA )
> local result, der, nsg, tblMGclasses, orders, tblMG,
>     tblMGfusttblMGA, tblMGclasses, pos, M, MimG, tblMGafusttblGA, tblGA,
>     outer, inv, filt, other, primes, p;
> result:= [];
> der:= ClassPositionsOfDerivedSubgroup( tblMGA );
> nsg:= ClassPositionsOfNormalSubgroups( tblMGA );
> tblMGclasses:= SizesConjugacyClasses( tblMGA );
> orders:= OrdersClassRepresentatives( tblMGA );
> if Length( der ) < NrConjugacyClasses( tblMGA ) then
> # Look for tables of normal subgroups of the form $M.G$.
> for tblMG in Filtered( List( NamesOfFusionSources( tblMGA ),
>     CharacterTable ), x -> x <> fail ) do
>     tblMGfusttblMGA:= GetFusionMap( tblMG, tblMGA );
>     tblMGclasses:= SizesConjugacyClasses( tblMG );
>     pos:= Position( nsg, Set( tblMGfusttblMGA ) );
>     if pos <> fail and

```



```

[ "2.U4(3).2_1", "2.U4(3).(2^2)_{13*3*}", "U4(3).(2^2)_{133}", 3 ]
[ "2.U4(3).2_1", "2.U4(3).(2^2)_{133}", "U4(3).(2^2)_{133}", 3 ]
[ "3.U3(8)", "3.U3(8).3_1", "U3(8).3_1", 2 ]
[ "3.U3(8)", "3.U3(8).6", "U3(8).6", 2 ]
[ "3.U3(8)", "3.U3(8).6", "U3(8).6", 3 ]
[ "3.U3(8).2", "3.U3(8).6", "U3(8).6", 2 ]
[ "5^(1+2):8:4", "2.HS.2N5", "HS.2N5", 5 ]
[ "6.A6", "6.A6.2_1", "3.A6.2_1", 3 ]
[ "6.A6", "6.A6.2_1", "A6.2_1", 3 ]
[ "6.Fi22", "6.Fi22.2", "3.Fi22.2", 3 ]
[ "6.Fi22", "6.Fi22.2", "Fi22.2", 3 ]
[ "Isoclinic(2.U4(3).2_1)", "2.U4(3).(2^2)_{1*2*2}", "U4(3).(2^2)_{122}", 3 ]
[ "Isoclinic(2.U4(3).2_1)", "2.U4(3).(2^2)_{1*3*3}", "U4(3).(2^2)_{133}", 3 ]

```

The smallest example in this list is $2.A_6.2_1$, the double cover of the symmetric group on six points. The 3-modular table of this group looks as follows.

```

gap> Display( CharacterTable( "2.A6.2_1" ) mod 3 );
2.A6.2_1mod3

```

2	5	5	4	3	1	1	4	4	3
3	2	2	1	1	.
5	1	1	.	.	1	1	.	.	.

1a	2a	4a	8a	5a	10a	2b	4b	8b	
2P	1a	1a	2a	4a	5a	5a	1a	2a	4a
3P	1a	2a	4a	8a	5a	10a	2b	4b	8b
5P	1a	2a	4a	8a	1a	2a	2b	4b	8b

X.1	1	1	1	1	1	1	1	1	1
X.2	1	1	1	1	1	1	-1	-1	-1
X.3	6	6	-2	2	1	1	.	.	.
X.4	4	4	.	-2	-1	-1	2	-2	.
X.5	4	4	.	-2	-1	-1	-2	2	.
X.6	9	9	1	1	-1	-1	3	3	-1
X.7	9	9	1	1	-1	-1	-3	-3	1
X.8	4	-4	.	.	-1	1	.	.	.
X.9	12	-12	.	.	2	-2	.	.	.

We see that the two faithful irreducible characters vanish on the three classes outside $2.A_6$.

For the groups in the above list, the function `BrauerTableOfTypeMGA` can be used to construct the p -modular tables of $M.G.A$ from the tables of $M.G$ and $G.A$, for the given special primes p . The computations can be performed as follows.

```

gap> for input in cases do
>   p:= input[4];
>   modtblMG:= CharacterTable( input[1] ) mod p;
>   ordtblMGA:= CharacterTable( input[2] );
>   modtblGA:= CharacterTable( input[3] ) mod p;
>   name:= Concatenation( Identifier( ordtblMGA ), " mod ", String(p) );
>   if ForAll( [ modtblMG, modtblGA ], IsCharacterTable ) then
>     poss:= BrauerTableOfTypeMGA( modtblMG, modtblGA, ordtblMGA );
>     modlib:= ordtblMGA mod p;
>     if IsCharacterTable( modlib ) then
>       trans:= TransformingPermutationsCharacterTables( poss.table,

```

```

>         modlib );
>     if not IsRecord( trans ) then
>         Print( "#E computed table and library table for ", name,
>             " differ\n" );
>         fi;
>     else
>         Print( "#I no library table for ", name, "\n" );
>         fi;
>     else
>         Print( "#I not all input tables for ", name, " available\n" );
>         fi;
>     od;
#I not all input tables for 2.L2(49).2_2 mod 7 available
#I not all input tables for 2.L2(81).2_1 mod 3 available
#I not all input tables for 2.L2(81).4_1 mod 3 available
#I not all input tables for 2.L2(81).4_1 mod 3 available

```

The examples $2.A_6.2_1$, $2.L_2(25).2_2$, and $2.L_2(49).2_2$ belong to the infinite series of semilinear groups $\Sigma L(2, p^2)$, for odd primes p . All groups in this series have the property that all faithful irreducible characters vanish on the p -regular classes outside $SL(2, p^2)$. (Cf. Section 2.5 for another property of the groups in this series.)

5 Examples for the Type $G.S_3$

5.1 Small Examples

The symmetric group S_4 on four points has the form $G.S_3$ where G is the Klein four group V_4 , $G.2$ is the dihedral group D_8 of order 8, and $G.3$ is the alternating group A_4 . The trivial character of A_4 extends twofold to S_4 , in the same way as the trivial character of V_4 extends to the dihedral group. The nontrivial linear characters of A_4 induce irreducibly to S_4 . The irreducible degree three character of A_4 is induced from any of the three nontrivial linear characters of V_4 , it extends to S_4 in the same way as the unique constituent of the restriction to V_4 that is invariant in the chosen D_8 extends to D_8 .

```

gap> c2:= CharacterTable( "Cyclic", 2 );;
gap> t:= c2 * c2;;
gap> tC:= CharacterTable( "Dihedral", 8 );;
gap> tK:= CharacterTable( "Alternating", 4 );;
gap> tfustC:= PossibleClassFusions( t, tC );
[ [ 1, 3, 4, 4 ], [ 1, 3, 5, 5 ], [ 1, 4, 3, 4 ], [ 1, 4, 4, 3 ],
  [ 1, 5, 3, 5 ], [ 1, 5, 5, 3 ] ]
gap> StoreFusion( t, tfustC[1], tC );
gap> tfustK:= PossibleClassFusions( t, tK );
[ [ 1, 2, 2, 2 ] ]
gap> StoreFusion( t, tfustK[1], tK );
gap> elms:= PossibleActionsForTypeGS3( t, tC, tK );
[ (3,4) ]
gap> new:= CharacterTableOfTypeGS3( t, tC, tK, elms[1], "S4" );
rec( table := CharacterTable( "S4" ), tblCfustblKC := [ 1, 4, 2, 2, 5 ],
      tblKfustblKC := [ 1, 2, 3, 3 ] )
gap> Display( new.table );
S4

```

```

      2 3 3 . 2 2
      3 1 . 1 . .

      1a 2a 3a 4a 2b
2P 1a 1a 3a 2a 1a
3P 1a 2a 1a 4a 2b

X.1  1 1 1 1 1
X.2  1 1 1 -1 -1
X.3  3 -1 . 1 -1
X.4  3 -1 . -1 1
X.5  2 2 -1 . .

```

The case $e > 1$ occurs in the following example. We choose G the cyclic group of order two, $G.C$ the cyclic group of order six, $G.K$ the quaternion group of order eight, and construct the character table of $G.F = SL_2(3)$, with $F \cong A_4$.

We get three extensions of the trivial character of $G.K$ to $G.F$, a degree three character induced from the nontrivial linear characters of $G.K$, and three extensions of the irreducible degree 2 character of $G.K$.

```

gap> t:= CharacterTable( "Cyclic", 2 );;
gap> tC:= CharacterTable( "Cyclic", 6 );;
gap> tK:= CharacterTable( "Quaternionic", 8 );;
gap> tfustC:= PossibleClassFusions( t, tC );
[ [ 1, 4 ] ]
gap> StoreFusion( t, tfustC[1], tC );
gap> tfustK:= PossibleClassFusions( t, tK );
[ [ 1, 3 ] ]
gap> StoreFusion( t, tfustK[1], tK );
gap> elms:= PossibleActionsForTypeGS3( t, tC, tK );
[ (2,5,4) ]
gap> new:= CharacterTableOfTypeGS3( t, tC, tK, elms[1], "SL(2,3)" );
rec( table := CharacterTable( "SL(2,3)" ),
     tblCfusttblKC := [ 1, 4, 5, 3, 6, 7 ], tblKfusttblKC := [ 1, 2, 3, 2, 2 ] )
gap> Display( new.table );
SL(2,3)

```

```

      2 3 2 3 1 1 1 1
      3 1 . 1 1 1 1 1

      1a 4a 2a 6a 3a 3b 6b
2P 1a 2a 1a 3a 3b 3a 3b
3P 1a 4a 2a 2a 1a 1a 2a

X.1  1 1 1 1 1 1 1
X.2  1 1 1 A /A A /A
X.3  1 1 1 /A A /A A
X.4  3 -1 3 . . .
X.5  2 . -2 /A -A -/A A
X.6  2 . -2 1 -1 -1 1
X.7  2 . -2 A -/A -A /A

```

```

A = E(3)
  = (-1+sqrt(-3))/2 = b3

```

5.2 Atlas Tables of the Type $G.S_3$

We demonstrate the construction of all those ordinary and modular character tables in the GAP Character Table Library that are of the type $G.S_3$ where G is a simple group or a central extension of a simple group whose character table is contained in the ATLAS. Here is the list of `Identifier` values needed for accessing the input tables and the known library tables corresponding to the output.

```
gap> listGS3:= [
> [ "U3(5)",      "U3(5).2",      "U3(5).3",      "U3(5).S3"      ],
> [ "3.U3(5)",   "3.U3(5).2",   "3.U3(5).3",   "3.U3(5).S3"   ],
> [ "L3(4)",     "L3(4).2_2",  "L3(4).3",     "L3(4).3.2_2"  ],
> [ "L3(4)",     "L3(4).2_3",  "L3(4).3",     "L3(4).3.2_3"  ],
> [ "3.L3(4)",   "3.L3(4).2_2", "3.L3(4).3",   "3.L3(4).3.2_2" ],
> [ "2^2.L3(4)", "2^2.L3(4).2_2", "2^2.L3(4).3", "2^2.L3(4).3.2_2" ],
> [ "2^2.L3(4)", "2^2.L3(4).2_3", "2^2.L3(4).3", "2^2.L3(4).3.2_3" ],
> [ "U6(2)",     "U6(2).2",    "U6(2).3",     "U6(2).3.2"    ],
> [ "3.U6(2)",   "3.U6(2).2",  "3.U6(2).3",   "3.U6(2).3.2"  ],
> [ "2^2.U6(2)", "2^2.U6(2).2", "2^2.U6(2).3", "2^2.U6(2).3.2" ],
> [ "08+(2)",    "08+(2).2",   "08+(2).3",    "08+(2).3.2"   ],
> [ "2^2.08+(2)", "2^2.08+(2).2", "2^2.08+(2).3", "2^2.08+(2).3.2" ],
> [ "L3(7)",     "L3(7).2",    "L3(7).3",     "L3(7).S3"     ],
> [ "3.L3(7)",   "3.L3(7).2",  "3.L3(7).3",   "3.L3(7).S3"   ],
> [ "U3(8)",     "U3(8).2",    "U3(8).3_2",   "U3(8).S3"     ],
> [ "3.U3(8)",   "3.U3(8).2",  "3.U3(8).3_2", "3.U3(8).S3"   ],
> [ "U3(11)",    "U3(11).2",   "U3(11).3",    "U3(11).S3"    ],
> [ "3.U3(11)",  "3.U3(11).2", "3.U3(11).3",  "3.U3(11).S3"  ],
> [ "08+(3)",    "08+(3).2_2", "08+(3).3",    "08+(3).S3"    ],
> [ "2E6(2)",    "2E6(2).2",   "2E6(2).3",    "2E6(2).S3"    ],
> [ "2^2.2E6(2)", "2^2.2E6(2).2", "2^2.2E6(2).3", "2^2.2E6(2).S3" ],
> ];;
```

(For G one of $L_3(4)$, $U_6(2)$, $O_8^+(2)$, and ${}^2E_6(2)$, the tables of $2^2.G$, $2^2.G.2$, and $2^2.G.3$ can be constructed with the methods described in Section 3.4 and Section 3.1, respectively.)

Analogously, the automorphism groups of $L_3(4)$ and $O_8^+(3)$ have factor groups isomorphic with S_3 ; in these cases, we choose $G = L_3(4).2_1$ and $G = O_8^+(3).2_{111}^2$, respectively.

```
gap> Append( listGS3, [
> [ "L3(4).2_1",      "L3(4).2^2",      "L3(4).6",      "L3(4).D12"      ],
> [ "2^2.L3(4).2_1",  "2^2.L3(4).2^2",  "2^2.L3(4).6",  "2^2.L3(4).D12"  ],
> [ "08+(3).(2^2)_{111}", "08+(3).D8",      "08+(3).A4",    "08+(3).S4"      ],
> ] );
```

In all these cases, the required table automorphism of $G.3$ is uniquely determined. We first compute the ordinary character table of $G.S_3$ and then the p -modular tables, for all prime divisors p of the order of G such that the GAP Character Table Library contains the necessary p -modular input tables.

In each case, we compare the computed character tables with the ones in the GAP Character Table Library. Note that in order to avoid conflicts of the class fusions that arise in the construction with the class fusions that are already stored on the library tables, we choose identifiers for the result tables that are different from the identifiers of the library tables.

```
gap> ProcessGS3Example:= function( t, tC, tK, identifier, pi )
>   local tF, lib, trans, p, tmodp, tCmodp, tKmodp, modtF;
>
>   tF:= CharacterTableOfTypeGS3( t, tC, tK, pi,
```

```

> Concatenation( identifier, "new" );
> lib:= CharacterTable( identifier );
> if lib <> fail then
>   trans:= TransformingPermutationsCharacterTables( tF.table, lib );
>   if not IsRecord( trans ) then
>     Print( "#E computed table and library table for '", identifier,
>           "' differ\n" );
>   fi;
> else
>   Print( "#I no library table for '", identifier, "'\n" );
>   fi;
> StoreFusion( tC, tF.tblCfusttblKC, tF.table );
> StoreFusion( tK, tF.tblKfusttblKC, tF.table );
> for p in Set( Factors( Size( t ) ) ) do
>   tmodp := t mod p;
>   tCmodp:= tC mod p;
>   tKmodp:= tK mod p;
>   if IsCharacterTable( tmodp ) and
>     IsCharacterTable( tCmodp ) and
>     IsCharacterTable( tKmodp ) then
>     modtF:= CharacterTableOfTypeGS3( tmodp, tCmodp, tKmodp,
>                                     tF.table,
>                                     Concatenation( identifier, "mod", String( p ) ) );
>     if Length( Irr( modtF.table ) ) <>
>       Length( Irr( modtF.table )[1] ) then
>       Print( "#E nonsquare result table for '",
>             identifier, " mod ", p, "'\n" );
>     elif lib <> fail and IsCharacterTable( lib mod p ) then
>       trans:= TransformingPermutationsCharacterTables( modtF.table,
>                                                         lib mod p );
>       if not IsRecord( trans ) then
>         Print( "#E computed table and library table for '",
>               identifier, " mod ", p, "' differ\n" );
>       fi;
>     else
>       Print( "#I no library table for '", identifier, " mod ",
>             p, "'\n" );
>     fi;
>   else
>     Print( "#I not all inputs available for '", identifier,
>           " mod ", p, "'\n" );
>   fi;
> od;
> end;;

```

Now we call the function for the examples in the list.

```

gap> for input in listGS3 do
>   t := CharacterTable( input[1] );
>   tC:= CharacterTable( input[2] );
>   tK:= CharacterTable( input[3] );
>   identifier:= input[4];
>   elms:= PossibleActionsForTypeGS3( t, tC, tK );
>   if Length( elms ) = 1 then
>     ProcessGS3Example( t, tC, tK, identifier, elms[1] );

```

```

>     else
>       Print( "#I ", Length( elms ), " actions possible for '",
>           identifier, "'\n" );
>     fi;
>   od;
#I not all inputs available for '08+(3).S3 mod 3'
#I not all inputs available for '2E6(2).S3 mod 2'
#I not all inputs available for '2E6(2).S3 mod 3'
#I not all inputs available for '2E6(2).S3 mod 5'
#I not all inputs available for '2E6(2).S3 mod 7'
#I not all inputs available for '2E6(2).S3 mod 11'
#I not all inputs available for '2E6(2).S3 mod 13'
#I not all inputs available for '2E6(2).S3 mod 17'
#I not all inputs available for '2E6(2).S3 mod 19'
#I not all inputs available for '2^2.2E6(2).S3 mod 2'
#I not all inputs available for '2^2.2E6(2).S3 mod 3'
#I not all inputs available for '2^2.2E6(2).S3 mod 5'
#I not all inputs available for '2^2.2E6(2).S3 mod 7'
#I not all inputs available for '2^2.2E6(2).S3 mod 11'
#I not all inputs available for '2^2.2E6(2).S3 mod 13'
#I not all inputs available for '2^2.2E6(2).S3 mod 17'
#I not all inputs available for '2^2.2E6(2).S3 mod 19'
#I not all inputs available for '08+(3).S4 mod 3'

```

Also the ordinary character table of the automorphic extension of the simple ATLAS group $O_8^+(3)$ by A_4 can be constructed with the same approach. Here we get four possible permutations, which lead to essentially the same character table.

```

gap> input:= [ "08+(3)", "08+(3).3", "08+(3).(2^2)_{111}", "08+(3).A4" ];;
gap> t := CharacterTable( input[1] );;
gap> tC:= CharacterTable( input[2] );;
gap> tK:= CharacterTable( input[3] );;
gap> identifier:= input[4];;
gap> elms:= PossibleActionsForTypeGS3( t, tC, tK );;
gap> Length( elms );
4
gap> differ:= MovedPoints( Group( List( elms, x -> x / elms[1] ) ) );;
gap> List( elms, x -> RestrictedPerm( x, differ ) );
[ (118,216,169)(119,217,170)(120,218,167)(121,219,168),
  (118,216,170)(119,217,169)(120,219,168)(121,218,167),
  (118,217,169)(119,216,170)(120,218,168)(121,219,167),
  (118,217,170)(119,216,169)(120,219,167)(121,218,168) ]
gap> poss:= List( elms, pi -> CharacterTableOfTypeGS3( t, tC, tK, pi,
>     Concatenation( identifier, "new" ) ) );;
gap> lib:= CharacterTable( identifier );;
gap> ForAll( poss, r -> IsRecord(
>     TransformingPermutationsCharacterTables( r.table, lib ) ) );;
true

```

Also the construction of the p -modular tables of $O_8^+(3).A_4$ works.

```

gap> ProcessGS3Example( t, tC, tK, identifier, elms[1] );;
#I not all inputs available for '08+(3).A4 mod 3'

```

6 Examples for the Type $G.2^2$

6.1 The Character Table of $A_6.2^2$

As the first example, we consider the automorphism group $\text{Aut}(A_6) \cong A_6.2^2$ of the alternating group A_6 on six points.

In this case, the triple of actions on the subgroups $A_6.2_i$ is uniquely determined by the condition on the number of conjugacy classes in Section 3.3.

```
gap> tblG:= CharacterTable( "A6" );;
gap> tblsG2:= List( [ "A6.2_1", "A6.2_2", "A6.2_3" ], CharacterTable );;
gap> List( tblsG2, NrConjugacyClasses );
[ 11, 11, 8 ]
gap> possact:= List( tblsG2, x -> Filtered( Elements(
> AutomorphismsOfTable( x ) ), y -> Order( y ) <= 2 ) );
[ [ (), (3,4)(7,8)(10,11) ], [ (), (8,9), (5,6)(10,11), (5,6)(8,9)(10,11) ],
  [ (), (7,8) ] ]
```

Note that $n_1 = n_2$ implies $f_1 = f_2$, and $n_1 - n_3 = 3$ implies $f_1 - f_3 = 2$, so we get $f_1 = 3$ and $f_3 = 1$, and $A_6.2^2$ has $2 \cdot 11 - 3 \cdot 3 = 2 \cdot 8 - 3 \cdot 1 = 13$ classes.

(The compatibility on the classes inside A_6 yields only that the classes 3 and 4 of $A_6.2_1 \cong S_6$ must be fused in $A_6.2^2$, as well as the classes 5 and 6 of $A_6.2_2 \cong \text{PGL}(2,9)$.)

```
gap> List( tblsG2, x -> GetFusionMap( tblG, x ) );
[ [ 1, 2, 3, 4, 5, 6, 6 ], [ 1, 2, 3, 3, 4, 5, 6 ], [ 1, 2, 3, 3, 4, 5, 5 ] ]
```

These arguments are used by the GAP function `PossibleActionsForTypeGV4`, which returns the list of all possible triples of permutations such that the i -th permutation describes the action of $A_6.2^2$ on the classes of $A_6.2_i$.

```
gap> acts:= PossibleActionsForTypeGV4( tblG, tblsG2 );
[ [ (3,4)(7,8)(10,11), (5,6)(8,9)(10,11), (7,8) ] ]
```

For the given actions, the GAP function `PossibleCharacterTablesOfTypeGV4` then computes the possibilities for the character table of $A_6.2^2$; in this case, the result is unique.

```
gap> poss:= PossibleCharacterTablesOfTypeGV4( tblG, tblsG2, acts[1], "A6.2^2" );
[ rec(
  G2fusGV4 := [ [ 1, 2, 3, 3, 4, 5, 6, 6, 7, 8, 8 ],
                [ 1, 2, 3, 4, 5, 5, 9, 10, 10, 11, 11 ],
                [ 1, 2, 3, 4, 5, 12, 13, 13 ] ],
  table := CharacterTable( "A6.2^2" ) ) ]
gap> IsRecord( TransformingPermutationsCharacterTables( poss[1].table,
> CharacterTable( "A6.2^2" ) ) );
true
```

Finally, possible p -modular tables can be computed from the p -modular input tables and the ordinary table of $A_6.2^2$; here we show this for $p = 3$.

```
gap> PossibleCharacterTablesOfTypeGV4( tblG mod 3,
> List( tblsG2, t -> t mod 3 ), poss[1].table );
[ rec(
  G2fusGV4 := [ [ 1, 2, 3, 4, 5, 5, 6 ], [ 1, 2, 3, 4, 4, 7, 8, 8, 9, 9 ],
                [ 1, 2, 3, 4, 10, 11, 11 ] ], table := BrauerTable( "A6.2^2", 3 ) )
]
```

6.2 Atlas Tables of the Type $G.2^2$ – Easy Cases

We demonstrate the construction of all those ordinary and modular character tables in the GAP Character Table Library that are of the type $G.2^2$ where G is a simple group or a central extension of a simple group whose character table is contained in the ATLAS. Here is the list of `Identifier` values needed for accessing the input tables and the result tables.

(The construction of the character table of $O_8^+(3).2_{111}^2$ is more involved and will be described in Section 6.10. The construction of the character tables of groups of the type $2.L_3(4).2^2$ and $6.L_3(4).2^2$ is described in the sections 6.4 and 6.5, respectively. The construction of the character tables of groups of the type $2.U_4(3).2^2$ is described in Section 6.6.)

```
gap> listGV4:= [
> [ "A6", "A6.2_1", "A6.2_2", "A6.2_3", "A6.2^2" ],
> [ "3.A6", "3.A6.2_1", "3.A6.2_2", "3.A6.2_3", "3.A6.2^2" ],
> [ "L2(25)", "L2(25).2_1", "L2(25).2_2", "L2(25).2_3", "L2(25).2^2" ],
> [ "L3(4)", "L3(4).2_1", "L3(4).2_2", "L3(4).2_3", "L3(4).2^2" ],
> [ "2^2.L3(4)", "2^2.L3(4).2_1", "2^2.L3(4).2_2", "2^2.L3(4).2_3",
> "2^2.L3(4).2^2" ],
> [ "3.L3(4)", "3.L3(4).2_1", "3.L3(4).2_2", "3.L3(4).2_3", "3.L3(4).2^2" ],
> [ "U4(3)", "U4(3).2_1", "U4(3).2_2", "U4(3).2_3",
> "U4(3).(2^2)_{122}" ],
> [ "U4(3)", "U4(3).2_1", "U4(3).2_3", "U4(3).2_3'",
> "U4(3).(2^2)_{133}" ],
> [ "3_1.U4(3)", "3_1.U4(3).2_1", "3_1.U4(3).2_2", "3_1.U4(3).2_3",
> "3_1.U4(3).(2^2)_{122}" ],
> [ "3_2.U4(3)", "3_2.U4(3).2_1", "3_2.U4(3).2_3", "3_2.U4(3).2_3'",
> "3_2.U4(3).(2^2)_{133}" ],
> [ "L2(49)", "L2(49).2_1", "L2(49).2_2", "L2(49).2_3", "L2(49).2^2" ],
> [ "L2(81)", "L2(81).2_1", "L2(81).2_2", "L2(81).2_3", "L2(81).2^2" ],
> [ "L3(9)", "L3(9).2_1", "L3(9).2_2", "L3(9).2_3", "L3(9).2^2" ],
> [ "08+(3)", "08+(3).2_1", "08+(3).2_2", "08+(3).2_3",
> "08+(3).(2^2)_{122}" ],
> [ "08-(3)", "08-(3).2_1", "08-(3).2_2", "08-(3).2_3", "08-(3).2^2" ],
> ];;
```

Analogously, the automorphism groups $L_3(4).D_{12}$ of $L_3(4)$ and $U_4(3).D_8$ of $U_4(3)$, and the subgroup $O_8^+(3).D_8$ of the automorphism group $O_8^+(3).S_4$ have factor groups that are isomorphic with 2^2 ; in these cases, we choose $G = L_3(4).3$, $G = U_4(3).2_1$, and $G = O_8^+(3).2_1$, respectively.

Also the group $2^2.L_3(4).D_{12}$ has a factor group isomorphic with 2^2 . Note that the character tables of $L_3(4).D_{12}$ and $2^2.L_3(4).D_{12}$ have been constructed already in Section 5.2.

The automorphism groups of $L_4(4)$ and $U_4(5)$ have the structure $L_4(4).2^2$ and $U_4(5).2^2$, respectively; their tables are contained in the GAP Character Table Library but not in the ATLAS.

```
gap> Append( listGV4, [
> [ "L3(4).3", "L3(4).6", "L3(4).3.2_2", "L3(4).3.2_3", "L3(4).D12" ],
> [ "2^2.L3(4).3", "2^2.L3(4).6", "2^2.L3(4).3.2_2", "2^2.L3(4).3.2_3",
> "2^2.L3(4).D12" ],
> [ "U4(3).2_1", "U4(3).4", "U4(3).(2^2)_{122}", "U4(3).(2^2)_{133}",
> "U4(3).D8" ],
> [ "08+(3).2_1", "08+(3).(2^2)_{111}", "08+(3).(2^2)_{122}", "08+(3).4",
> "08+(3).D8" ],
> [ "L4(4)", "L4(4).2_1", "L4(4).2_2", "L4(4).2_3", "L4(4).2^2" ],
> [ "U4(5)", "U4(5).2_1", "U4(5).2_2", "U4(5).2_3", "U4(5).2^2" ],
> ] );
```

Now we proceed in two steps, the computation of the possible ordinary character tables from the ordinary tables of the relevant subgroups, and then the computation of the Brauer tables from the Brauer tables of the relevant subgroups and from the ordinary table of the group.

The following function first computes the possible triples of actions on the subgroups $G.2_i$, using the function `PossibleActionsForTypeGV4`. Then the union of the candidate tables for these actions is computed, this list is returned in the end. and representatives of classes of permutation equivalent candidates are inspected further with consistency checks. If there is a unique solution up to permutation equivalence, this table is compared with the one that is contained in the GAP Character Table Library.

```

gap> ConstructOrdinaryGV4Table:= function( tblG, tblsG2, name, lib )
>   local acts, nam, poss, reps, i, trans;
>
>   # Compute the possible actions for the ordinary tables.
>   acts:= PossibleActionsForTypeGV4( tblG, tblsG2 );
>   # Compute the possible ordinary tables for the given actions.
>   nam:= Concatenation( "new", name );
>   poss:= Concatenation( List( acts, triple ->
>     PossibleCharacterTablesOfTypeGV4( tblG, tblsG2, triple, nam ) ) );
>   # Test the possibilities for permutation equivalence.
>   reps:= RepresentativesCharacterTables( poss );
>   if 1 < Length( reps ) then
>     Print( "#I ", name, ": ", Length( reps ),
>           " equivalence classes\n" );
>   elif Length( reps ) = 0 then
>     Print( "#E ", name, ": no solution\n" );
>   else
>     # Compare the computed table with the library table.
>     if not IsCharacterTable( lib ) then
>       Print( "#I no library table for ", name, "\n" );
>       PrintToLib( name, poss[1].table );
>       for i in [ 1 .. 3 ] do
>         Print( LibraryFusion( tblsG2[i],
>                               rec( name:= name, map:= poss[1].G2fusGV4[i] ) ) );
>       od;
>     else
>       trans:= TransformingPermutationsCharacterTables( poss[1].table,
>                                                         lib );
>       if not IsRecord( trans ) then
>         Print( "#E computed table and library table for ", name,
>               " differ\n" );
>       fi;
>       # Compare the computed fusions with the stored ones.
>       if List( poss[1].G2fusGV4, x -> OnTuples( x, trans.columns ) )
>         <> List( tblsG2, x -> GetFusionMap( x, lib ) ) then
>         Print( "#E computed and stored fusions for ", name,
>               " differ\n" );
>       fi;
>     fi;
>   return poss;
> end;;

```

The following function computes, for all those prime divisors p of the group order in question such that the p -modular Brauer tables of the subgroups $G.2_i$ are available, the possible p -modular Brauer

tables. If the solution is unique up to permutation equivalence, it is compared with the table that is contained in the GAP Character Table Library.

It may happen (even in the case that the ordinary character table is unique up to permutation equivalence) that some candidates for the ordinary character table are excluded due to information provided by some p -modular table. In this case, a message is printed, and the ordinary character table from the GAP Character Table Library is checked again under the additional restrictions.

```

gap> ConstructModularGV4Tables:= function( tblG, tblsG2, ordposs,
>                                     ordlibtblGV4 )
>   local name, modposs, primes, checkordinary, i, record, p, tmodp,
>         t2modp, poss, modlib, trans, reps;
>
>   if not IsCharacterTable( ordlibtblGV4 ) then
>     Print( "#I no ordinary library table ...\n" );
>     return [];
>   fi;
>   name:= Identifier( ordlibtblGV4 );
>   modposs:= [];
>   primes:= Set( Factors( Size( tblG ) ) );
>   ordposs:= ShallowCopy( ordposs );
>   checkordinary:= false;
>   for i in [ 1 .. Length( ordposs ) ] do
>     modposs[i]:= [];
>     record:= ordposs[i];
>     for p in primes do
>       tmodp := tblG mod p;
>       t2modp:= List( tblsG2, t2 -> t2 mod p );
>       if IsCharacterTable( tmodp ) and
>         ForAll( t2modp, IsCharacterTable ) then
>         poss:= PossibleCharacterTablesOfTypeGV4( tmodp, t2modp,
>           record.table, record.G2fusGV4 );
>         poss:= RepresentativesCharacterTables( poss );
>         if Length( poss ) = 0 then
>           Print( "#I excluded cand. ", i, " (out of ",
>             Length( ordposs ), ") for ", name, " by ", p,
>             "-mod. table\n" );
>           Unbind( ordposs[i] );
>           Unbind( modposs[i] );
>           checkordinary:= true;
>           break;
>         elif Length( poss ) = 1 then
>           # Compare the computed table with the library table.
>           modlib:= ordlibtblGV4 mod p;
>           if IsCharacterTable( modlib ) then
>             trans:= TransformingPermutationsCharacterTables(
>               poss[1].table, modlib );
>             if not IsRecord( trans ) then
>               Print( "#E computed table and library table for ",
>                 name, " mod ", p, " differ\n" );
>             fi;
>           else
>             Print( "#I no library table for ",
>               name, " mod ", p, "\n" );
>             PrintToLib( name, poss[1].table );

```

```

>         fi;
>     else
>         Print( "#I ", name, " mod ", p, ": ", Length( poss ),
>             " equivalence classes\n" );
>     fi;
>     Add( modposs[i], poss );
> else
>     Print( "#I not all input tables for ", name, " mod ", p,
>         " available\n" );
>     primes:= Difference( primes, [ p ] );
>     fi;
> od;
> od;
> if checkordinary then
>     # Test whether the ordinary table is admissible.
>     ordposs:= Compacted( ordposs );
>     modposs:= Compacted( modposs );
>     reps:= RepresentativesCharacterTables( ordposs );
>     if 1 < Length( reps ) then
>         Print( "#I ", name, ": ", Length( reps ),
>             " equivalence classes (ord. table)\n" );
>     elif Length( reps ) = 0 then
>         Print( "#E ", name, ": no solution (ord. table)\n" );
>     else
>         # Compare the computed table with the library table.
>         trans:= TransformingPermutationsCharacterTables(
>             ordposs[1].table, ordlibtblGV4 );
>         if not IsRecord( trans ) then
>             Print( "#E computed table and library table for ", name,
>                 " differ\n" );
>         fi;
>         # Compare the computed fusions with the stored ones.
>         if List( ordposs[1].G2fusGV4, x -> OnTuples( x, trans.columns ) )
>             <> List( tblsG2, x -> GetFusionMap( x, ordlibtblGV4 ) ) then
>             Print( "#E computed and stored fusions for ", name,
>                 " differ\n" );
>         fi;
>     fi;
>     return rec( ordinary:= ordposs, modular:= modposs );
> end;;

```

Finally, here is the loop over the list of tables.

```

gap> for input in listGV4 do
>     tblG := CharacterTable( input[1] );
>     tblsG2 := List( input{ [ 2 .. 4 ] }, CharacterTable );
>     lib := CharacterTable( input[5] );
>     poss := ConstructOrdinaryGV4Table( tblG, tblsG2, input[5], lib );
>     ConstructModularGV4Tables( tblG, tblsG2, poss, lib );
> od;
#I excluded cand. 2 (out of 2) for L3(4).2^2 by 3-mod. table
#I excluded cand. 2 (out of 8) for 2^2.L3(4).2^2 by 7-mod. table
#I excluded cand. 3 (out of 8) for 2^2.L3(4).2^2 by 5-mod. table
#I excluded cand. 4 (out of 8) for 2^2.L3(4).2^2 by 5-mod. table

```

```

#I excluded cand. 5 (out of 8) for 2^2.L3(4).2^2 by 5-mod. table
#I excluded cand. 6 (out of 8) for 2^2.L3(4).2^2 by 5-mod. table
#I excluded cand. 7 (out of 8) for 2^2.L3(4).2^2 by 7-mod. table
#I excluded cand. 2 (out of 2) for 3.L3(4).2^2 by 3-mod. table
#I not all input tables for L2(49).2^2 mod 7 available
#I not all input tables for L2(81).2^2 mod 3 available
#I excluded cand. 2 (out of 2) for L3(9).2^2 by 7-mod. table
#I not all input tables for 08+(3).(2^2)_{122} mod 3 available
#I not all input tables for 08-(3).2^2 mod 2 available
#I not all input tables for 08-(3).2^2 mod 3 available
#I not all input tables for 08-(3).2^2 mod 5 available
#I not all input tables for 08-(3).2^2 mod 7 available
#I not all input tables for 08-(3).2^2 mod 13 available
#I not all input tables for 08-(3).2^2 mod 41 available
#I excluded cand. 2 (out of 2) for L3(4).D12 by 3-mod. table
#I excluded cand. 2 (out of 2) for 2^2.L3(4).D12 by 7-mod. table
#I not all input tables for 08+(3).D8 mod 3 available
#I not all input tables for L4(4).2^2 mod 3 available
#I not all input tables for L4(4).2^2 mod 5 available
#I not all input tables for L4(4).2^2 mod 7 available
#I not all input tables for L4(4).2^2 mod 17 available
#I not all input tables for U4(5).2^2 mod 2 available
#I not all input tables for U4(5).2^2 mod 3 available
#I not all input tables for U4(5).2^2 mod 5 available
#I not all input tables for U4(5).2^2 mod 7 available
#I not all input tables for U4(5).2^2 mod 13 available

```

The groups $3.A_6.2^2$, $3.L_3(4).2^2$, and $3_2.U_4(3).(2^2)_{133}$ have also the structure $M.G.A$, with $M.G$ equal to $3.A_6.2_3$, $3.L_3(4).2_1$, and $3_2.U_4(3).2_3$, respectively, and $G.A$ equal to $A_6.2^2$, $L_3(4).2^2$, and $U_4(3).(2^2)_{133}$, respectively (see Section 4.3).

Similarly, the group $L_3(4).D_{12}$ has also the structure $G.S_3$, with $G = L_3(4).2_1$, $G.2 = L_3(4).2^2$, and $G.3 = L_3(4).6$, respectively (see Section 5.2).

6.3 The Character Table of $S_4(9).2^2$ (September 2011)

The available functions yield two possibilities for the ordinary character table of $S_4(9).2^2$.

```

gap> tblG:= CharacterTable( "S4(9)" );;
gap> tblsG2:= List( [ "S4(9).2_1", "S4(9).2_2", "S4(9).2_3" ],
> CharacterTable );;
gap> lib:= CharacterTable( "S4(9).2^2" );;
gap> poss:= ConstructOrdinaryGV4Table( tblG, tblsG2, "newS4(9).2^2", lib );;
#I newS4(9).2^2: 2 equivalence classes
gap> poss:= RepresentativesCharacterTables( poss );;

```

The two candidates differ w. r. t. the action of $S_4(9).2^2$ on the classes of element order 80 in $S_4(9).2_2$. In the two possible tables, each element of order 80 is conjugate to its third power or to its 13-th power, respectively.

```

gap> order80:= PositionsProperty( OrdersClassRepresentatives( tblsG2[2] ),
> x -> x = 80 );
[ 98, 99, 100, 101, 102, 103, 104, 105 ]
gap> List( poss, r -> r.G2fusGV4[2]{ order80 } );
[ [ 77, 77, 78, 79, 80, 78, 79, 80 ], [ 77, 78, 79, 79, 80, 80, 78 ] ]

```

```

gap> PowerMap( tblsG2[2], 3 ){ order80 };
[ 99, 98, 103, 104, 105, 100, 101, 102 ]
gap> PowerMap( tblsG2[2], 13 ){ order80 };
[ 102, 105, 101, 100, 98, 104, 103, 99 ]

```

We claim that the first candidate is the correct one. For that, first note that $S_4(9).2_2$ is the extension of the simple group by a diagonal automorphism. (An easy way to see this is that for any subgroup of $S_4(9)$ isomorphic with $S_2(81) \cong L_2(81)$, the extension by a diagonal automorphism contains elements of order 80 –this group is isomorphic with $\text{PGL}(2, 81)$ – and only $S_4(9).2_2$ contains elements of order 80.)

```

gap> List( tblsG2, x -> 80 in OrdersClassRepresentatives( x ) );
[ false, true, false ]

```

Now the field automorphism of $S_4(9).2_2$ maps each element x of order 80 in $S_4(9).2_2$ to a conjugate of x^3 .

```

gap> tbl:= poss[1].table;;
gap> IsRecord( TransformingPermutationsCharacterTables( tbl, lib ) );
true

```

6.4 The Character Tables of Groups of the Type $2.L_3(4).2^2$ (June 2010)

The outer automorphism group of the group $L_3(4)$ is a dihedral group of order 12; its Sylow 2-subgroups are Klein four groups, so there is a unique almost simple group H of the type $2.L_3(4).2^2$, up to isomorphism. In this section, we construct the character tables of the double covers of this group with the approach from Section 3.3.

The group H has three subgroups of index two, of the types $L_3(4).2_1$, $L_3(4).2_2$, and $L_3(4).2_3$, respectively. So any double cover of H contains one subgroup of each of the types $2.L_3(4).2_1$, $2.L_3(4).2_2$, and $2.L_3(4).2_3$, and there are two isoclinic variants of each of these group to consider, see Section 2.5. So we start with eight different inputs for the construction of the character tables of double covers.

```

gap> names:= List( [ 1 .. 3 ],
> i -> Concatenation( "2.L3(4).2_", String( i ) ) );
gap> tbls:= List( names, CharacterTable );
[ CharacterTable( "2.L3(4).2_1" ), CharacterTable( "2.L3(4).2_2" ),
  CharacterTable( "2.L3(4).2_3" ) ]
gap> isos:= List( names, nam -> CharacterTable( Concatenation( nam, "*" ) ) );
[ CharacterTable( "Isoclinic(2.L3(4).2_1)" ),
  CharacterTable( "Isoclinic(2.L3(4).2_2)" ),
  CharacterTable( "Isoclinic(2.L3(4).2_3)" ) ]
gap> inputs:= [
> [ tbls[1], tbls[2], tbls[3], "2.L3(4).(2^2)_{123}" ],
> [ tbls[1], isos[2], tbls[3], "2.L3(4).(2^2)_{12*3}" ],
> [ tbls[1], tbls[2], isos[3], "2.L3(4).(2^2)_{123*}" ],
> [ tbls[1], isos[2], isos[3], "2.L3(4).(2^2)_{12*3*}" ],
> [ isos[1], tbls[2], tbls[3], "2.L3(4).(2^2)_{1*23}" ],
> [ isos[1], isos[2], tbls[3], "2.L3(4).(2^2)_{1*2*3}" ],
> [ isos[1], tbls[2], isos[3], "2.L3(4).(2^2)_{1*23*}" ],
> [ isos[1], isos[2], isos[3], "2.L3(4).(2^2)_{1*2*3*}" ] ];
gap> tblG:= CharacterTable( "2.L3(4)" );
gap> result:= [];
gap> for input in inputs do

```

```

> tblsG2:= input{ [ 1 .. 3 ] };
> lib:= CharacterTable( input[4] );
> poss:= ConstructOrdinaryGV4Table( tblG, tblsG2, input[4], lib );
> ConstructModularGV4Tables( tblG, tblsG2, poss, lib );
> Append( result, RepresentativesCharacterTables( poss ) );
> od;
#I excluded cand. 2 (out of 8) for 2.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 3 (out of 8) for 2.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 4 (out of 8) for 2.L3(4).(2^2)_{123} by 7-mod. table
#I excluded cand. 5 (out of 8) for 2.L3(4).(2^2)_{123} by 7-mod. table
#I excluded cand. 6 (out of 8) for 2.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 7 (out of 8) for 2.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 2 (out of 8) for 2.L3(4).(2^2)_{12*3*} by 5-mod. table
#I excluded cand. 3 (out of 8) for 2.L3(4).(2^2)_{12*3*} by 5-mod. table
#I excluded cand. 4 (out of 8) for 2.L3(4).(2^2)_{12*3*} by 7-mod. table
#I excluded cand. 5 (out of 8) for 2.L3(4).(2^2)_{12*3*} by 7-mod. table
#I excluded cand. 6 (out of 8) for 2.L3(4).(2^2)_{12*3*} by 5-mod. table
#I excluded cand. 7 (out of 8) for 2.L3(4).(2^2)_{12*3*} by 5-mod. table
#I excluded cand. 2 (out of 8) for 2.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 3 (out of 8) for 2.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 4 (out of 8) for 2.L3(4).(2^2)_{1*2*3} by 7-mod. table
#I excluded cand. 5 (out of 8) for 2.L3(4).(2^2)_{1*2*3} by 7-mod. table
#I excluded cand. 6 (out of 8) for 2.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 7 (out of 8) for 2.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 2 (out of 8) for 2.L3(4).(2^2)_{1*23*} by 5-mod. table
#I excluded cand. 3 (out of 8) for 2.L3(4).(2^2)_{1*23*} by 5-mod. table
#I excluded cand. 4 (out of 8) for 2.L3(4).(2^2)_{1*23*} by 7-mod. table
#I excluded cand. 5 (out of 8) for 2.L3(4).(2^2)_{1*23*} by 7-mod. table
#I excluded cand. 6 (out of 8) for 2.L3(4).(2^2)_{1*23*} by 5-mod. table
#I excluded cand. 7 (out of 8) for 2.L3(4).(2^2)_{1*23*} by 5-mod. table
gap> result:= List( result, x -> x.table );
[ CharacterTable( "new2.L3(4).(2^2)_{123}" ),
  CharacterTable( "new2.L3(4).(2^2)_{12*3*}" ),
  CharacterTable( "new2.L3(4).(2^2)_{123*}" ),
  CharacterTable( "new2.L3(4).(2^2)_{12*3*}" ),
  CharacterTable( "new2.L3(4).(2^2)_{1*23}" ),
  CharacterTable( "new2.L3(4).(2^2)_{1*2*3}" ),
  CharacterTable( "new2.L3(4).(2^2)_{1*23*}" ),
  CharacterTable( "new2.L3(4).(2^2)_{1*2*3*}" ) ]

```

We get exactly one character table for each input. For each of these tables, there are three possibilities to form an isoclinic table, corresponding to the three subgroups of index two. It turns out that the eight solutions form two orbits under forming some isoclinic table. Tables in different orbits are essentially different, already their numbers of conjugacy classes differ.

```

gap> List( result, NrConjugacyClasses );
[ 39, 33, 33, 39, 33, 39, 39, 33 ]
gap> t:= result[1];;
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
> x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );;
gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );;
gap> List( iso, x -> PositionProperty( result, y ->
> TransformingPermutationsCharacterTables( x, y ) <> fail ) );;
[ 4, 7, 6 ]
gap> t:= result[2];;

```

```

gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
> x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );;
gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );;
gap> List( iso, x -> PositionProperty( result, y ->
> TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 3, 8, 5 ]

```

Up to now, it is not clear that the character tables we have constructed are really the character tables of some groups. The existence of groups for the first orbit of character tables can be established as follows.

The group $U_6(2).2$ contains a maximal subgroup M of the type $L_3(4).2^2$, see [CCN⁺85, p. 115]. Its derived subgroup M' of the type $L_3(4)$ lies inside $U_6(2)$, and we claim that the preimage of M' under the natural epimorphism from $2.U_6(2)$ to $U_6(2)$ is a double cover of $L_3(4)$. Unfortunately, $L_3(4)$ admits class fusions into $2.U_6(2)$, so this criterion cannot be used.

```

gap> l34:= CharacterTable( "L3(4)" );;
gap> u:= CharacterTable( "U6(2)" );;
gap> 2u:= CharacterTable( "2.U6(2)" );;
gap> cand:= PossibleClassFusions( l34, 2u );
[ [ 1, 5, 12, 16, 22, 22, 23, 23, 41, 41 ],
  [ 1, 5, 12, 22, 16, 22, 23, 23, 41, 41 ],
  [ 1, 5, 12, 22, 22, 16, 23, 23, 41, 41 ] ]
gap> OrdersClassRepresentatives( l34 );
[ 1, 2, 3, 4, 4, 4, 5, 5, 7, 7 ]

```

Consider the three classes of elements of order four in $L_3(4)$. Under the possible fusions into $2.U_6(2)$, they are mapped to the classes 16 and 22, which are preimages of the classes 10 and 14 (4C and 4G) of $U_6(2)$. Note that the maximal subgroups of type $L_3(4).2$ in $U_6(2)$ extend to $L_3(4).6$ type subgroups in $U_6(2).3$, and the three classes 4C, 4D, 4E form one orbit under the action of an outer automorphism of order three of $U_6(2)$.

```

gap> GetFusionMap( 2u, u ){ [ 16, 22 ] };
[ 10, 14 ]
gap> ClassNames( u, "ATLAS" ){ [ 10, 14 ] };
[ "4C", "4G" ]
gap> GetFusionMap( u, CharacterTable( "U6(2).3" ) );
[ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19,
  20, 21, 22, 23, 24, 24, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36,
  36, 36, 37, 38, 39, 40 ]

```

This means that any $L_3(4)$ type subgroup of $U_6(2)$ that extends to an $L_3(4).6$ type subgroup in $U_6(2).3$ either contains elements from all three classes 4C, 4D, 4E of $U_6(2)$, or contains no element from these classes. Thus we know that any double cover of $U_6(2).2$ contains a double cover of $L_3(4).2^2$. Only the first of our result tables admits a class fusion into the table of $2.U_6(2).2$.

```

gap> 2u2:= CharacterTable( "2.U6(2).2" );;
gap> fus:= List( result, x -> PossibleClassFusions( x, 2u2 ) );;
gap> List( fus, Length );
[ 4, 0, 0, 0, 0, 0, 0, 0 ]

```

As a consequence, the fourth result table is established as that of a maximal subgroup of the group isoclinic to $2.U_6(2).2$.

```

gap> 2u2iso:= CharacterTableIsoclinic( 2u2 );;
gap> fus:= List( result, x -> PossibleClassFusions( x, 2u2iso ) );;
gap> List( fus, Length );
[ 0, 0, 0, 4, 0, 0, 0, 0 ]

```

Similarly, the group $HS.2$ contains a maximal subgroup M of the type $L_3(4).2^2$, see [CCN⁺85, p. 80]. Its derived subgroup M' of the type $L_3(4)$ lies inside HS , and the preimage of M' under the natural epimorphism from $2.HS$ to HS is a double cover of $L_3(4)$, because $L_3(4)$ does not admit a class fusion into $2.HS.2$.

```
gap> h2:= CharacterTable( "HS.2" );;
gap> 2h2:= CharacterTable( "2.HS.2" );;
gap> PossibleClassFusions( 134, 2h2 );
[ ]
```

Only the fifth of our result tables admits a class fusion into $2.HS.2$, which means that $2.L_3(4).(2^2)_{1*23}$ is a subgroup of $2.HS.2$, and the eighth result table $-2.L_3(4).(2^2)_{1*2*3*-}$ admits a class fusion into the isoclinic variant of $2.HS.2$. This shows the existence of groups for the tables from the second orbit.

```
gap> fus:= List( result, x -> PossibleClassFusions( x, 2h2 ) );;
gap> List( fus, Length );
[ 0, 0, 0, 0, 4, 0, 0, 0 ]
gap> 2h2iso:= CharacterTableIsoclinic( 2h2 );;
gap> fus:= List( result, x -> PossibleClassFusions( x, 2h2iso ) );;
gap> List( fus, Length );
[ 0, 0, 0, 0, 0, 0, 0, 4 ]
```

6.5 The Character Tables of Groups of the Type $6.L_3(4).2^2$ (October 2011)

We have two approaches for constructing the character tables of these groups.

First, we may regard them as normal products of the three normal subgroups of index two, each of them having the structure $6.L_3(4).2$, and use the approach from Section 3.3, as we did in Section 6.4 for the groups of the structure $2.L_3(4).2^2$.

Second, we may use the approach from Section 3.1. Note that the factor group $L_3(4).2^2$ contains each of the three groups $L_3(4).2_i$ as a subgroup, for $1 \leq i \leq 3$, and the groups of the type $6.L_3(4).2_1$ have a centre of order six, whereas the centres of the $6.L_3(4).2_2$ and $6.L_3(4).2_3$ type groups have order two. For that, the character tables of the subgroups $6.L_3(4).2_1$ and $6.L_3(4).2_1^*$ are needed, as well as the character tables of the eight possible factor groups $2.L_3(4).2^2$; the latter tables are known from Section 6.4.

We show both approaches. (The second approach is better suited for storing the character tables in the Character Table Library, since the irreducible characters need not be stored, and since the Brauer tables of the groups can be derived from the Brauer tables of the compound tables.)

```
gap> tbls:= List( [ "1", "2", "3" ],
> i -> CharacterTable( Concatenation( "6.L3(4).2_", i ) ) );
[ CharacterTable( "6.L3(4).2_1" ), CharacterTable( "6.L3(4).2_2" ),
  CharacterTable( "6.L3(4).2_3" ) ]
gap> isos:= List( [ "1", "2", "3" ],
> i -> CharacterTable( Concatenation( "6.L3(4).2_", i, "*" ) ) );
[ CharacterTable( "Isoclinic(6.L3(4).2_1)" ),
  CharacterTable( "Isoclinic(6.L3(4).2_2)" ),
  CharacterTable( "Isoclinic(6.L3(4).2_3)" ) ]
gap> inputs:= [
> [ tbls[1], tbls[2], tbls[3], "6.L3(4).(2^2)_{123}" ],
> [ tbls[1], isos[2], tbls[3], "6.L3(4).(2^2)_{12*3}" ],
> [ tbls[1], tbls[2], isos[3], "6.L3(4).(2^2)_{123*}" ],
> [ tbls[1], isos[2], isos[3], "6.L3(4).(2^2)_{12*3*}" ],
```

```

> [ isos[1], tbls[2], tbls[3], "6.L3(4).(2^2)_{1*23}" ],
> [ isos[1], isos[2], tbls[3], "6.L3(4).(2^2)_{1*2*3}" ],
> [ isos[1], tbls[2], isos[3], "6.L3(4).(2^2)_{1*23*}" ],
> [ isos[1], isos[2], isos[3], "6.L3(4).(2^2)_{1*2*3*}" ] ];;
gap> tblG:= CharacterTable( "6.L3(4)" );;
gap> result:= [];;
gap> for input in inputs do
>   tblsG2:= input{ [ 1 .. 3 ] };
>   lib:= CharacterTable( input[4] );
>   poss:= ConstructOrdinaryGV4Table( tblG, tblsG2, input[4], lib );
>   ConstructModularGV4Tables( tblG, tblsG2, poss, lib );
>   Append( result, RepresentativesCharacterTables( poss ) );
> od;
#I excluded cand. 2 (out of 8) for 6.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 3 (out of 8) for 6.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 4 (out of 8) for 6.L3(4).(2^2)_{123} by 7-mod. table
#I excluded cand. 5 (out of 8) for 6.L3(4).(2^2)_{123} by 7-mod. table
#I excluded cand. 6 (out of 8) for 6.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 7 (out of 8) for 6.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 2 (out of 8) for 6.L3(4).(2^2)_{12*3*} by 5-mod. table
#I excluded cand. 3 (out of 8) for 6.L3(4).(2^2)_{12*3*} by 5-mod. table
#I excluded cand. 4 (out of 8) for 6.L3(4).(2^2)_{12*3*} by 7-mod. table
#I excluded cand. 5 (out of 8) for 6.L3(4).(2^2)_{12*3*} by 7-mod. table
#I excluded cand. 6 (out of 8) for 6.L3(4).(2^2)_{12*3*} by 5-mod. table
#I excluded cand. 7 (out of 8) for 6.L3(4).(2^2)_{12*3*} by 5-mod. table
#I excluded cand. 2 (out of 8) for 6.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 3 (out of 8) for 6.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 4 (out of 8) for 6.L3(4).(2^2)_{1*2*3} by 7-mod. table
#I excluded cand. 5 (out of 8) for 6.L3(4).(2^2)_{1*2*3} by 7-mod. table
#I excluded cand. 6 (out of 8) for 6.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 7 (out of 8) for 6.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 2 (out of 8) for 6.L3(4).(2^2)_{1*23*} by 5-mod. table
#I excluded cand. 3 (out of 8) for 6.L3(4).(2^2)_{1*23*} by 5-mod. table
#I excluded cand. 4 (out of 8) for 6.L3(4).(2^2)_{1*23*} by 7-mod. table
#I excluded cand. 5 (out of 8) for 6.L3(4).(2^2)_{1*23*} by 7-mod. table
#I excluded cand. 6 (out of 8) for 6.L3(4).(2^2)_{1*23*} by 5-mod. table
#I excluded cand. 7 (out of 8) for 6.L3(4).(2^2)_{1*23*} by 5-mod. table
gap> result:= List( result, x -> x.table );
[ CharacterTable( "new6.L3(4).(2^2)_{123}" ),
  CharacterTable( "new6.L3(4).(2^2)_{12*3*}" ),
  CharacterTable( "new6.L3(4).(2^2)_{123*}" ),
  CharacterTable( "new6.L3(4).(2^2)_{12*3*}" ),
  CharacterTable( "new6.L3(4).(2^2)_{1*23}" ),
  CharacterTable( "new6.L3(4).(2^2)_{1*2*3}" ),
  CharacterTable( "new6.L3(4).(2^2)_{1*23*}" ),
  CharacterTable( "new6.L3(4).(2^2)_{1*2*3*}" ) ]

```

As in Section 6.4, we get exactly one character table for each input, and the eight solutions lie in two orbits under isoclinism.

```

gap> List( result, NrConjugacyClasses );
[ 59, 53, 53, 59, 53, 59, 59, 53 ]
gap> t:= result[1];;
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
>   x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );;

```

```

gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );;
gap> List( iso, x -> PositionProperty( result, y ->
>      TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 7, 6, 4 ]
gap> t:= result[2];;
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
>      x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );;
gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );;
gap> List( iso, x -> PositionProperty( result, y ->
>      TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 8, 5, 3 ]

```

Up to now, it is not clear that the character tables we have constructed are really the character tables of some groups. The existence of groups for the first orbit of character tables can be established as follows.

We have shown in Section 6.4 that the maximal subgroups M of the type $L_3(4).2^2$ in $U_6(2).2$ lift to double covers $2.L_3(4).2^2$ in $2.U_6(2).2$. The preimages of these groups under the natural epimorphism from $6.U_6(2).2$ have the structure $6.L_3(4).2^2$, where the derived subgroup is the six-fold cover of $L_3(4)$; this follows from the fact that $6.U_6(2)$ does not admit a class fusion from the double cover $2.L_3(4)$.

```

gap> 2l34:= CharacterTable( "2.L3(4)" );;
gap> 6u:= CharacterTable( "6.U6(2)" );;
gap> cand:= PossibleClassFusions( 2l34, 6u );
[ ]

```

This establishes the first and the fourth result as character tables of subgroups of $6.U_6(2)$ and its isoclinic variant, respectively.

```

gap> 6u2:= CharacterTable( "6.U6(2).2" );;
gap> fus:= List( result, x -> PossibleClassFusions( x, 6u2 ) );;
gap> List( fus, Length );
[ 8, 0, 0, 0, 0, 0, 0, 0 ]
gap> 6u2iso:= CharacterTableIsoclinic( 6u2 );;
gap> fus:= List( result, x -> PossibleClassFusions( x, 6u2iso ) );;
gap> List( fus, Length );
[ 0, 0, 0, 8, 0, 0, 0, 0 ]

```

Similarly, the group $G_2(4).2$ contains a maximal subgroup M of the type $3.L_3(4).2^2$, see [CCN⁺85, p. 97]. Its derived subgroup M' of the type $3.L_3(4)$ lies inside $G_2(4)$, and the preimage of M' under the natural epimorphism from $2.G_2(4)$ to $G_2(4)$ is a double cover of $3.L_3(4)$, because $3.L_3(4)$ does not admit a class fusion into $2.G_2(4).2$.

```

gap> 3l34:= CharacterTable( "3.L3(4)" );;
gap> g2:= CharacterTable( "G2(4).2" );;
gap> 2g2:= CharacterTable( "2.G2(4).2" );;
gap> PossibleClassFusions( 3l34, 2g2 );
[ ]

```

Only the third and eighth of our result tables admit a class fusion into $2.G_2(4).2$ and its isoclinic variant, respectively. This shows the existence of groups for the tables from the second orbit.

```

gap> fus:= List( result, x -> PossibleClassFusions( x, 2g2 ) );;
gap> List( fus, Length );
[ 0, 0, 16, 0, 0, 0, 0, 0 ]

```

```

gap> 2g2iso:= CharacterTableIsoclinic( 2g2 );;
gap> fus:= List( result, x -> PossibleClassFusions( x, 2g2iso ) );;
gap> List( fus, Length );
[ 0, 0, 0, 0, 0, 0, 0, 16 ]

```

Now we try the second approach and compare the results.

```

gap> names:= [ "L3(4).(2^2)_{123}", "L3(4).(2^2)_{12*3}",
>             "L3(4).(2^2)_{123*}", "L3(4).(2^2)_{12*3*}" ];;
gap> inputs1:= List( names, nam -> [ "6.L3(4).2_1", "2.L3(4).2_1",
>             Concatenation( "2.", nam ), Concatenation( "6.", nam ) ] );;
gap> names:= List( names, nam -> ReplacedString( nam, "1", "1*" ) );;
gap> inputs2:= List( names, nam -> [ "6.L3(4).2_1*", "2.L3(4).2_1*",
>             Concatenation( "2.", nam ), Concatenation( "6.", nam ) ] );;
gap> inputs:= Concatenation( inputs1, inputs2 );
[ [ "6.L3(4).2_1", "2.L3(4).2_1", "2.L3(4).(2^2)_{123}",
    "6.L3(4).(2^2)_{123}" ],
  [ "6.L3(4).2_1", "2.L3(4).2_1", "2.L3(4).(2^2)_{12*3}",
    "6.L3(4).(2^2)_{12*3}" ],
  [ "6.L3(4).2_1", "2.L3(4).2_1", "2.L3(4).(2^2)_{123*}",
    "6.L3(4).(2^2)_{123*}" ],
  [ "6.L3(4).2_1", "2.L3(4).2_1", "2.L3(4).(2^2)_{12*3*}",
    "6.L3(4).(2^2)_{12*3*}" ],
  [ "6.L3(4).2_1*", "2.L3(4).2_1*", "2.L3(4).(2^2)_{1*23}",
    "6.L3(4).(2^2)_{1*23}" ],
  [ "6.L3(4).2_1*", "2.L3(4).2_1*", "2.L3(4).(2^2)_{1*2*3}",
    "6.L3(4).(2^2)_{1*2*3}" ],
  [ "6.L3(4).2_1*", "2.L3(4).2_1*", "2.L3(4).(2^2)_{1*23*}",
    "6.L3(4).(2^2)_{1*23*}" ],
  [ "6.L3(4).2_1*", "2.L3(4).2_1*", "2.L3(4).(2^2)_{1*2*3*}",
    "6.L3(4).(2^2)_{1*2*3*}" ] ]
gap> result2:= [];;
gap> for input in inputs do
>   tblMG := CharacterTable( input[1] );
>   tblG  := CharacterTable( input[2] );
>   tblGA := CharacterTable( input[3] );
>   name  := Concatenation( "new", input[4] );
>   lib   := CharacterTable( input[4] );
>   poss:= ConstructOrdinaryMGATable( tblMG, tblG, tblGA, name, lib );
>   Append( result2, poss );
> od;
gap> result2:= List( result2, x -> x.table );
[ CharacterTable( "new6.L3(4).(2^2)_{123}" ),
  CharacterTable( "new6.L3(4).(2^2)_{12*3}" ),
  CharacterTable( "new6.L3(4).(2^2)_{123*}" ),
  CharacterTable( "new6.L3(4).(2^2)_{12*3*}" ),
  CharacterTable( "new6.L3(4).(2^2)_{1*23}" ),
  CharacterTable( "new6.L3(4).(2^2)_{1*2*3}" ),
  CharacterTable( "new6.L3(4).(2^2)_{1*23*}" ),
  CharacterTable( "new6.L3(4).(2^2)_{1*2*3*}" ) ]
gap> trans:= List( [ 1 .. 8 ], i ->
>   TransformingPermutationsCharacterTables( result[i], result2[i] ) );;
gap> ForAll( trans, IsRecord );
true

```

6.6 The Character Tables of Groups of the Type $2.U_4(3).2^2$ (February 2012)

The outer automorphism group of the group $U_4(3)$ is a dihedral group of order 8. There are two almost simple groups of the type $U_4(3).2^2$, up to isomorphism, denoted as $U_4(3).(2^2)_{122}$ and $U_4(3).(2^2)_{133}$, respectively. Note that $U_4(3).2_1$ is the extension by the central involution of the outer automorphism group of $U_4(3)$, the other two subgroups of index two in $U_4(3).(2^2)_{122}$ are $U_4(3).2_2$ and $U_4(3).2'_2$, respectively, and the other two subgroups of index two in $U_4(3).(2^2)_{133}$ are $U_4(3).2_3$ and $U_4(3).2'_3$, respectively.

Since $\text{Aut}(U_4(3))$ possesses a double cover (see [CCN⁺85, p. 52]), double covers of $U_4(3).(2^2)_{122}$ and $U_4(3).(2^2)_{133}$ exist.

First we deal with the double covers of $U_4(3).(2^2)_{122}$. Any such group contains one subgroup of the type $2.U_4(3).2_1$ and two subgroups of the type $2.U_4(3).2_2$, and there are two isoclinic variants of each of these group to consider, see Section 2.5. Thus we start with six different inputs for the construction of the character tables of double covers.

```
gap> tbls:= List( [ "1", "2", "2'" ], i ->
>   CharacterTable( Concatenation( "2.U4(3).2_", i ) ) );
gap> isos:= List( [ "1", "2", "2'" ], i ->
>   CharacterTable( Concatenation( "Isoclinic(2.U4(3).2_", i, ")" ) ) );
gap> inputs:= [
> [ tbls[1], tbls[2], tbls[3], "2.U4(3).(2^2)_{122}" ],
> [ isos[1], tbls[2], tbls[3], "2.U4(3).(2^2)_{1*22}" ],
> [ tbls[1], isos[2], tbls[3], "2.U4(3).(2^2)_{12*2}" ],
> [ isos[1], isos[2], tbls[3], "2.U4(3).(2^2)_{1*2*2}" ],
> [ tbls[1], isos[2], isos[3], "2.U4(3).(2^2)_{12*2*}" ],
> [ isos[1], isos[2], isos[3], "2.U4(3).(2^2)_{1*2*2*}" ] ];
gap> tblG:= CharacterTable( "2.U4(3)" );
gap> result:= [];
gap> for input in inputs do
>   tblsG2:= input{ [ 1 .. 3 ] };
>   lib:= CharacterTable( input[4] );
>   poss:= ConstructOrdinaryGV4Table( tblG, tblsG2, input[4], lib );
>   ConstructModularGV4Tables( tblG, tblsG2, poss, lib );
>   Append( result, RepresentativesCharacterTables( poss ) );
> od;
gap> result:= List( result, x -> x.table );
[ CharacterTable( "new2.U4(3).(2^2)_{122}" ),
  CharacterTable( "new2.U4(3).(2^2)_{1*22}" ),
  CharacterTable( "new2.U4(3).(2^2)_{12*2}" ),
  CharacterTable( "new2.U4(3).(2^2)_{1*2*2}" ),
  CharacterTable( "new2.U4(3).(2^2)_{12*2*}" ),
  CharacterTable( "new2.U4(3).(2^2)_{1*2*2*}" ) ]
```

We get exactly one character table for each input. For each of these tables, there are three possibilities to form an isoclinic table, corresponding to the three subgroups of index two. It turns out that the six solutions form two orbits under forming some isoclinic table. Tables in different orbits are essentially different, already their numbers of conjugacy classes differ.

```
gap> List( result, NrConjugacyClasses );
[ 87, 102, 102, 87, 87, 102 ]
gap> t:= result[1];
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
>   x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );
```

```

gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );;
gap> List( iso, x -> PositionProperty( result, y ->
>      TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 4, 4, 5 ]
gap> t:= result[2];;
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
>      x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );;
gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );;
gap> List( iso, x -> PositionProperty( result, y ->
>      TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 3, 3, 6 ]

```

Up to now, it is not clear that the character tables we have constructed are really the character tables of some groups. The existence of groups for the first orbit of character tables can be established as follows.

The group $O_8^+(3)$ contains maximal subgroups of the type $2.U_4(3).2^2$, see [CCN⁺85, p. 140]. Only the first of our result tables admits a class fusion into the table of $O_8^+(3)$.

```

gap> u:= CharacterTable( "08+(3)" );;
gap> fus:= List( result, x -> PossibleClassFusions( x, u ) );;
gap> List( fus, Length );
[ 24, 0, 0, 0, 0, 0 ]

```

A table in the second orbit belongs to a maximal subgroup of $O_7(3).2$, see [CCN⁺85, p. 109].

```

gap> u:= CharacterTable( "07(3).2" );;
gap> fus:= List( result, x -> PossibleClassFusions( x, u ) );;
gap> List( fus, Length );
[ 0, 16, 0, 0, 0, 0 ]

```

Note that this subgroup of $O_7(3).2 \cong SO(7, 3)$ is the orthogonal group $GO_6^-(3)$.

Now we deal with the double covers of $U_4(3).(2^2)_{133}$. The constructions of the character tables are completely analogous to those in the case of $U_4(3).(2^2)_{122}$.

```

gap> tbls:= List( [ "1", "3", "3'" ],
>      i -> CharacterTable( Concatenation( "2.U4(3).2_", i ) ) );;
gap> isos:= List( [ "1", "3", "3'" ], i ->
>      CharacterTable( Concatenation( "Isoclinic(2.U4(3).2_", i, ")" ) ) );;
gap> inputs:= [
> [ tbls[1], tbls[2], tbls[3], "2.U4(3).(2^2)_{133}" ],
> [ isos[1], tbls[2], tbls[3], "2.U4(3).(2^2)_{1*33}" ],
> [ tbls[1], isos[2], tbls[3], "2.U4(3).(2^2)_{13*3}" ],
> [ isos[1], isos[2], tbls[3], "2.U4(3).(2^2)_{1*3*3}" ],
> [ tbls[1], isos[2], isos[3], "2.U4(3).(2^2)_{13*3*}" ],
> [ isos[1], isos[2], isos[3], "2.U4(3).(2^2)_{1*3*3*}" ] ];;
gap> tblG:= CharacterTable( "2.U4(3)" );;
gap> result:= [];;
gap> for input in inputs do
>   tblsG2:= input{ [ 1 .. 3 ] };
>   lib:= CharacterTable( input[4] );
>   poss:= ConstructOrdinaryGV4Table( tblG, tblsG2, input[4], lib );
>   ConstructModularGV4Tables( tblG, tblsG2, poss, lib );
>   Append( result, RepresentativesCharacterTables( poss ) );
> od;

```

```

#I excluded cand. 2 (out of 4) for 2.U4(3).(2^2)_{1*33} by 3-mod. table
#I excluded cand. 3 (out of 4) for 2.U4(3).(2^2)_{1*33} by 3-mod. table
#I excluded cand. 2 (out of 4) for 2.U4(3).(2^2)_{13*3} by 3-mod. table
#I excluded cand. 3 (out of 4) for 2.U4(3).(2^2)_{13*3} by 3-mod. table
#I excluded cand. 2 (out of 4) for 2.U4(3).(2^2)_{1*3*3*} by 3-mod. table
#I excluded cand. 3 (out of 4) for 2.U4(3).(2^2)_{1*3*3*} by 3-mod. table
gap> result:= List( result, x -> x.table );
[ CharacterTable( "new2.U4(3).(2^2)_{133}" ),
  CharacterTable( "new2.U4(3).(2^2)_{1*33}" ),
  CharacterTable( "new2.U4(3).(2^2)_{13*3}" ),
  CharacterTable( "new2.U4(3).(2^2)_{1*3*3*}" ),
  CharacterTable( "new2.U4(3).(2^2)_{13*3*}" ),
  CharacterTable( "new2.U4(3).(2^2)_{1*3*3*}" ) ]
gap> List( result, NrConjugacyClasses );
[ 69, 72, 72, 69, 69, 72 ]
gap> t:= result[1];
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
>   x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );
gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );
gap> List( iso, x -> PositionProperty( result, y ->
>   TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 4, 4, 5 ]
gap> t:= result[2];
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
>   x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );
gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );
gap> List( iso, x -> PositionProperty( result, y ->
>   TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 3, 3, 6 ]

```

6.7 The Character Tables of Groups of the Type $4_1.L_3(4).2^2$ (October 2011)

The situation with $4_1.L_3(4).2^2$ is analogous to that with $6.L_3(4).2^2$, see Section 6.5.

```

gap> tbls:= List( [ "1", "2", "3" ],
>   i -> CharacterTable( Concatenation( "4_1.L3(4).2_", i ) ) );
[ CharacterTable( "4_1.L3(4).2_1" ), CharacterTable( "4_1.L3(4).2_2" ),
  CharacterTable( "4_1.L3(4).2_3" ) ]
gap> isos:= List( [ "1", "2", "3" ],
>   i -> CharacterTable( Concatenation( "4_1.L3(4).2_", i, "*" ) ) );
[ CharacterTable( "Isoclinic(4_1.L3(4).2_1)" ),
  CharacterTable( "Isoclinic(4_1.L3(4).2_2)" ),
  CharacterTable( "4_1.L3(4).2_3*" ) ]

```

Note that the group $4_1.L_3(4).2_3$ has a centre of order four, so one cannot construct the isoclinic variant by calling the one argument version of `CharacterTableIsoclinic`.

```

gap> List( tbls, ClassPositionsOfCentre );
[ [ 1, 3 ], [ 1, 3 ], [ 1, 2, 3, 4 ] ]
gap> IsRecord( TransformingPermutationsCharacterTables( tbls[3],
>   CharacterTableIsoclinic( tbls[3] ) ) );
true

```

Again, we get eight different character tables, in two orbits.

```

gap> inputs:= [
> [ tbls[1], tbls[2], tbls[3], "4_1.L3(4).(2^2)_{123}" ],
> [ isos[1], tbls[2], tbls[3], "4_1.L3(4).(2^2)_{1*23}" ],
> [ tbls[1], isos[2], tbls[3], "4_1.L3(4).(2^2)_{12*3}" ],
> [ isos[1], isos[2], tbls[3], "4_1.L3(4).(2^2)_{1*2*3}" ],
> [ tbls[1], tbls[2], isos[3], "4_1.L3(4).(2^2)_{123*}" ],
> [ isos[1], tbls[2], isos[3], "4_1.L3(4).(2^2)_{1*23*}" ],
> [ tbls[1], isos[2], isos[3], "4_1.L3(4).(2^2)_{12*3*}" ],
> [ isos[1], isos[2], isos[3], "4_1.L3(4).(2^2)_{1*2*3*}" ] ];
gap> tblG:= CharacterTable( "4_1.L3(4)" );
gap> result:= [];
gap> for input in inputs do
>   tblsG2:= input{ [ 1 .. 3 ] };
>   lib:= CharacterTable( input[4] );
>   poss:= ConstructOrdinaryGV4Table( tblG, tblsG2, input[4], lib );
>   ConstructModularGV4Tables( tblG, tblsG2, poss, lib );
>   Append( result, RepresentativesCharacterTables( poss ) );
>   od;
#I excluded cand. 2 (out of 8) for 4_1.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 3 (out of 8) for 4_1.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 4 (out of 8) for 4_1.L3(4).(2^2)_{123} by 7-mod. table
#I excluded cand. 5 (out of 8) for 4_1.L3(4).(2^2)_{123} by 7-mod. table
#I excluded cand. 6 (out of 8) for 4_1.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 7 (out of 8) for 4_1.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 2 (out of 8) for 4_1.L3(4).(2^2)_{1*23} by 5-mod. table
#I excluded cand. 3 (out of 8) for 4_1.L3(4).(2^2)_{1*23} by 5-mod. table
#I excluded cand. 4 (out of 8) for 4_1.L3(4).(2^2)_{1*23} by 7-mod. table
#I excluded cand. 5 (out of 8) for 4_1.L3(4).(2^2)_{1*23} by 7-mod. table
#I excluded cand. 6 (out of 8) for 4_1.L3(4).(2^2)_{1*23} by 5-mod. table
#I excluded cand. 7 (out of 8) for 4_1.L3(4).(2^2)_{1*23} by 5-mod. table
#I excluded cand. 2 (out of 8) for 4_1.L3(4).(2^2)_{12*3} by 5-mod. table
#I excluded cand. 3 (out of 8) for 4_1.L3(4).(2^2)_{12*3} by 5-mod. table
#I excluded cand. 4 (out of 8) for 4_1.L3(4).(2^2)_{12*3} by 7-mod. table
#I excluded cand. 5 (out of 8) for 4_1.L3(4).(2^2)_{12*3} by 7-mod. table
#I excluded cand. 6 (out of 8) for 4_1.L3(4).(2^2)_{12*3} by 5-mod. table
#I excluded cand. 7 (out of 8) for 4_1.L3(4).(2^2)_{12*3} by 5-mod. table
#I excluded cand. 2 (out of 8) for 4_1.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 3 (out of 8) for 4_1.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 4 (out of 8) for 4_1.L3(4).(2^2)_{1*2*3} by 7-mod. table
#I excluded cand. 5 (out of 8) for 4_1.L3(4).(2^2)_{1*2*3} by 7-mod. table
#I excluded cand. 6 (out of 8) for 4_1.L3(4).(2^2)_{1*2*3} by 5-mod. table
#I excluded cand. 7 (out of 8) for 4_1.L3(4).(2^2)_{1*2*3} by 5-mod. table
gap> result:= List( result, x -> x.table );
[ CharacterTable( "new4_1.L3(4).(2^2)_{123}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{1*23}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{12*3}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{1*2*3}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{123*}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{1*23*}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{12*3*}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{1*2*3*}" ) ]
gap> List( result, NrConjugacyClasses );
[ 48, 48, 48, 48, 42, 42, 42, 42 ]

```

```

gap> t:= result[1];;
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
> x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );;
gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );;
gap> List( iso, x -> PositionProperty( result, y ->
> TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 3, 2, 4 ]
gap> t:= result[5];;
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
> x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );;
gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );;
gap> List( iso, x -> PositionProperty( result, y ->
> TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 7, 6, 8 ]

```

Note that only two out of the eight tables of the type $2.L_3(4).2^2$ occur as factors of the eight tables.

```

gap> facts:= [ CharacterTable( "2.L3(4).(2^2)_{123}" ),
> CharacterTable( "2.L3(4).(2^2)_{123*}" ) ];;
gap> factresults:= List( result, t -> t / ClassPositionsOfCentre( t ) );;
gap> List( factresults, t -> PositionProperty( facts, f ->
> IsRecord( TransformingPermutationsCharacterTables( t, f ) ) ) );
[ 1, 1, 1, 1, 2, 2, 2, 2 ]

```

This is not surprising; note that for $1 \leq i \leq 2$, the two isoclinic variants of $4_1.L_3(4).2_i$ have isomorphic factor groups of the type $2.L_3(4).2_i$. (For $i = 3$, this is not the case.)

```

gap> test:= [ CharacterTable( "4_1.L3(4).2_1" ),
> CharacterTable( "4_1.L3(4).2_1*" ) ];;
gap> List( test, ClassPositionsOfCentre );
[ [ 1, 3 ], [ 1, 3 ] ]
gap> fact:= List( test, t -> t / ClassPositionsOfCentre( t ) );;
gap> IsRecord( TransformingPermutationsCharacterTables( fact[1], fact[2] ) );
true
gap> test:= [ CharacterTable( "4_1.L3(4).2_2" ),
> CharacterTable( "4_1.L3(4).2_2*" ) ];;
gap> List( test, ClassPositionsOfCentre );
[ [ 1, 3 ], [ 1, 3 ] ]
gap> fact:= List( test, t -> t / ClassPositionsOfCentre( t ) );;
gap> IsRecord( TransformingPermutationsCharacterTables( fact[1], fact[2] ) );
true

```

Now we try the second approach and compare the results. By the abovementioned asymmetry, it is clear that the tables are not uniquely determined by the input data.

```

gap> names:= [ "L3(4).(2^2)_{123}", "L3(4).(2^2)_{1*23}",
> "L3(4).(2^2)_{12*3}", "L3(4).(2^2)_{1*2*3}" ];;
gap> inputs1:= List( names, nam -> [ "4_1.L3(4).2_3", "2.L3(4).2_3",
> Concatenation( "2.", nam ), Concatenation( "4_1.", nam ) ] );;
gap> names:= List( names, nam -> ReplacedString( nam, "3", "3*" ) );;
gap> inputs2:= List( names, nam -> [ "4_1.L3(4).2_3*", "2.L3(4).2_3*",
> Concatenation( "2.", nam ), Concatenation( "4_1.", nam ) ] );;
gap> inputs:= Concatenation( inputs1, inputs2 );
[ [ "4_1.L3(4).2_3", "2.L3(4).2_3", "2.L3(4).(2^2)_{123}",
"4_1.L3(4).(2^2)_{123}" ],

```

```

[ "4_1.L3(4).2_3", "2.L3(4).2_3", "2.L3(4).(2^2)_{1*23}",
  "4_1.L3(4).(2^2)_{1*23}" ],
[ "4_1.L3(4).2_3", "2.L3(4).2_3", "2.L3(4).(2^2)_{12*3}",
  "4_1.L3(4).(2^2)_{12*3}" ],
[ "4_1.L3(4).2_3", "2.L3(4).2_3", "2.L3(4).(2^2)_{1*2*3}",
  "4_1.L3(4).(2^2)_{1*2*3}" ],
[ "4_1.L3(4).2_3*", "2.L3(4).2_3*", "2.L3(4).(2^2)_{123*}",
  "4_1.L3(4).(2^2)_{123*}" ],
[ "4_1.L3(4).2_3*", "2.L3(4).2_3*", "2.L3(4).(2^2)_{1*23*}",
  "4_1.L3(4).(2^2)_{1*23*}" ],
[ "4_1.L3(4).2_3*", "2.L3(4).2_3*", "2.L3(4).(2^2)_{12*3*}",
  "4_1.L3(4).(2^2)_{12*3*}" ],
[ "4_1.L3(4).2_3*", "2.L3(4).2_3*", "2.L3(4).(2^2)_{1*2*3*}",
  "4_1.L3(4).(2^2)_{1*2*3*}" ] ]
gap> result2:= [ ];;
gap> for input in inputs do
>   tblMG := CharacterTable( input[1] );
>   tblG  := CharacterTable( input[2] );
>   tblGA := CharacterTable( input[3] );
>   name  := Concatenation( "new", input[4] );
>   lib   := CharacterTable( input[4] );
>   poss:= ConstructOrdinaryMGATable( tblMG, tblG, tblGA, name, lib );
>   Append( result2, poss );
> od;
#E 4 possibilities for new4_1.L3(4).(2^2)_{123}
#E no solution for new4_1.L3(4).(2^2)_{1*23}
#E no solution for new4_1.L3(4).(2^2)_{12*3}
#E no solution for new4_1.L3(4).(2^2)_{1*2*3}
#E 4 possibilities for new4_1.L3(4).(2^2)_{123*}
#E no solution for new4_1.L3(4).(2^2)_{1*23*}
#E no solution for new4_1.L3(4).(2^2)_{12*3*}
#E no solution for new4_1.L3(4).(2^2)_{1*2*3*}
gap> Length( result2 );
8
gap> result2:= List( result2, x -> x.table );
[ CharacterTable( "new4_1.L3(4).(2^2)_{123}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{123}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{123}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{123}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{123*}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{123*}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{123*}" ),
  CharacterTable( "new4_1.L3(4).(2^2)_{123*}" ) ]
gap> List( result, t1 -> PositionsProperty( result2, t2 -> IsRecord(
>   TransformingPermutationsCharacterTables( t1, t2 ) ) ) );
[ [ 1 ], [ 4 ], [ 3 ], [ 2 ], [ 7 ], [ 6 ], [ 5 ], [ 8 ] ]

```

At the moment, I do not know interesting groups that contain one of the $4_1.L_3(4).2^2$ type groups and whose character tables are available.

6.8 The Character Tables of Groups of the Type $4_2.L_3(4).2^2$ (October 2011)

The situation with $4_2.L_3(4).2^2$ is analogous to that with $6.L_3(4).2^2$, see Section 6.5.

```

gap> tbls:= List( [ "1", "2", "3" ],
>   i -> CharacterTable( Concatenation( "4_2.L3(4).2_", i ) ) );
[ CharacterTable( "4_2.L3(4).2_1" ), CharacterTable( "4_2.L3(4).2_2" ),
  CharacterTable( "4_2.L3(4).2_3" ) ]
gap> isos:= List( [ "1", "2", "3" ],
>   i -> CharacterTable( Concatenation( "4_2.L3(4).2_", i, "*" ) ) );
[ CharacterTable( "Isoclinic(4_2.L3(4).2_1)" ),
  CharacterTable( "4_2.L3(4).2_2*" ),
  CharacterTable( "Isoclinic(4_2.L3(4).2_3)" ) ]

```

Note that the group $4_1.L_3(4).2_2$ has a centre of order four, so one cannot construct the isoclinic variant not by calling the one argument version of `CharacterTableIsoclinic`.

```

gap> List( tbls, ClassPositionsOfCentre );
[ [ 1, 3 ], [ 1, 2, 3, 4 ], [ 1, 3 ] ]
gap> IsRecord( TransformingPermutationsCharacterTables( tbls[2],
>   CharacterTableIsoclinic( tbls[2] ) ) );
true

```

Again, we get eight different character tables, in two orbits.

```

gap> inputs:= [
> [ tbls[1], tbls[2], tbls[3], "4_2.L3(4).(2^2)_{123}" ],
> [ isos[1], tbls[2], tbls[3], "4_2.L3(4).(2^2)_{1*23}" ],
> [ tbls[1], isos[2], tbls[3], "4_2.L3(4).(2^2)_{12*3}" ],
> [ tbls[1], tbls[2], isos[3], "4_2.L3(4).(2^2)_{123*}" ],
> [ isos[1], isos[2], tbls[3], "4_2.L3(4).(2^2)_{1*2*3}" ],
> [ isos[1], tbls[2], isos[3], "4_2.L3(4).(2^2)_{1*23*}" ],
> [ tbls[1], isos[2], isos[3], "4_2.L3(4).(2^2)_{12*3*}" ],
> [ isos[1], isos[2], isos[3], "4_2.L3(4).(2^2)_{1*2*3*}" ] ];;
gap> tblG:= CharacterTable( "4_2.L3(4)" );;
gap> result:= [];;
gap> for input in inputs do
>   tblsG2:= input{ [ 1 .. 3 ] };
>   lib:= CharacterTable( input[4] );
>   poss:= ConstructOrdinaryGV4Table( tblG, tblsG2, input[4], lib );
>   ConstructModularGV4Tables( tblG, tblsG2, poss, lib );
>   Append( result, RepresentativesCharacterTables( poss ) );
>   od;
#I excluded cand. 2 (out of 8) for 4_2.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 3 (out of 8) for 4_2.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 4 (out of 8) for 4_2.L3(4).(2^2)_{123} by 7-mod. table
#I excluded cand. 5 (out of 8) for 4_2.L3(4).(2^2)_{123} by 7-mod. table
#I excluded cand. 6 (out of 8) for 4_2.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 7 (out of 8) for 4_2.L3(4).(2^2)_{123} by 5-mod. table
#I excluded cand. 2 (out of 8) for 4_2.L3(4).(2^2)_{1*23} by 5-mod. table
#I excluded cand. 3 (out of 8) for 4_2.L3(4).(2^2)_{1*23} by 5-mod. table
#I excluded cand. 4 (out of 8) for 4_2.L3(4).(2^2)_{1*23} by 7-mod. table
#I excluded cand. 5 (out of 8) for 4_2.L3(4).(2^2)_{1*23} by 7-mod. table
#I excluded cand. 6 (out of 8) for 4_2.L3(4).(2^2)_{1*23} by 5-mod. table
#I excluded cand. 7 (out of 8) for 4_2.L3(4).(2^2)_{1*23} by 5-mod. table
#I excluded cand. 2 (out of 8) for 4_2.L3(4).(2^2)_{123*} by 5-mod. table
#I excluded cand. 3 (out of 8) for 4_2.L3(4).(2^2)_{123*} by 5-mod. table
#I excluded cand. 4 (out of 8) for 4_2.L3(4).(2^2)_{123*} by 7-mod. table
#I excluded cand. 5 (out of 8) for 4_2.L3(4).(2^2)_{123*} by 7-mod. table

```

```

#I excluded cand. 6 (out of 8) for 4_2.L3(4).(2^2)_{123*} by 5-mod. table
#I excluded cand. 7 (out of 8) for 4_2.L3(4).(2^2)_{123*} by 5-mod. table
#I excluded cand. 2 (out of 8) for 4_2.L3(4).(2^2)_{1*23*} by 5-mod. table
#I excluded cand. 3 (out of 8) for 4_2.L3(4).(2^2)_{1*23*} by 5-mod. table
#I excluded cand. 4 (out of 8) for 4_2.L3(4).(2^2)_{1*23*} by 7-mod. table
#I excluded cand. 5 (out of 8) for 4_2.L3(4).(2^2)_{1*23*} by 7-mod. table
#I excluded cand. 6 (out of 8) for 4_2.L3(4).(2^2)_{1*23*} by 5-mod. table
#I excluded cand. 7 (out of 8) for 4_2.L3(4).(2^2)_{1*23*} by 5-mod. table
gap> result:= List( result, x -> x.table );
[ CharacterTable( "new4_2.L3(4).(2^2)_{123}" ),
  CharacterTable( "new4_2.L3(4).(2^2)_{1*23}" ),
  CharacterTable( "new4_2.L3(4).(2^2)_{12*3}" ),
  CharacterTable( "new4_2.L3(4).(2^2)_{123*}" ),
  CharacterTable( "new4_2.L3(4).(2^2)_{1*2*3}" ),
  CharacterTable( "new4_2.L3(4).(2^2)_{1*23*}" ),
  CharacterTable( "new4_2.L3(4).(2^2)_{12*3*}" ),
  CharacterTable( "new4_2.L3(4).(2^2)_{1*2*3*}" ) ]
gap> List( result, NrConjugacyClasses );
[ 50, 50, 44, 50, 44, 50, 44, 44 ]
gap> t:= result[1];;
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
>   x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );;
gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );;
gap> List( iso, x -> PositionProperty( result, y ->
>   TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 4, 2, 6 ]
gap> t:= result[3];;
gap> nsg:= Filtered( ClassPositionsOfNormalSubgroups( t ),
>   x -> Sum( SizesConjugacyClasses( t ){ x } ) = Size( t ) / 2 );;
gap> iso:= List( nsg, x -> CharacterTableIsoclinic( t, x ) );;
gap> List( iso, x -> PositionProperty( result, y ->
>   TransformingPermutationsCharacterTables( x, y ) <> fail ) );
[ 7, 5, 8 ]

```

Note that only two out of the eight tables of the type $2.L_3(4).2^2$ occur as factors of the eight tables.

```

gap> facts:= [ CharacterTable( "2.L3(4).(2^2)_{123}" ),
>   CharacterTable( "2.L3(4).(2^2)_{12*3}" ) ];;
gap> factresults:= List( result, t -> t / ClassPositionsOfCentre( t ) );;
gap> List( factresults, t -> PositionProperty( facts, f ->
>   IsRecord( TransformingPermutationsCharacterTables( t, f ) ) ) );
[ 1, 1, 2, 1, 2, 1, 2, 2 ]

```

This is not surprising; note that for $i \in \{1, 3\}$, the two isoclinic variants of $4_1.L_3(4).2_i$ have isomorphic factor groups of the type $2.L_3(4).2_i$. (For $i = 2$, this is not the case.)

```

gap> test:= [ CharacterTable( "4_2.L3(4).2_1" ),
>   CharacterTable( "4_2.L3(4).2_1*" ) ];;
gap> List( test, ClassPositionsOfCentre );
[ [ 1, 3 ], [ 1, 3 ] ]
gap> fact:= List( test, t -> t / ClassPositionsOfCentre( t ) );;
gap> IsRecord( TransformingPermutationsCharacterTables( fact[1], fact[2] ) );
true
gap> test:= [ CharacterTable( "4_2.L3(4).2_3" ),
>   CharacterTable( "4_2.L3(4).2_3*" ) ];;

```

```

gap> List( test, ClassPositionsOfCentre );
[ [ 1, 3 ], [ 1, 3 ] ]
gap> fact:= List( test, t -> t / ClassPositionsOfCentre( t ) );
gap> IsRecord( TransformingPermutationsCharacterTables( fact[1], fact[2] ) );
true

```

Now we try the second approach and compare the results. By the abovementioned asymmetry, it is clear that the tables are not uniquely determined by the input data.

```

gap> names:= [ "L3(4).(2^2)_{123}", "L3(4).(2^2)_{1*23}",
>             "L3(4).(2^2)_{123*}", "L3(4).(2^2)_{1*23*}" ];;
gap> inputs1:= List( names, nam -> [ "4_2.L3(4).2_2", "2.L3(4).2_2",
>             Concatenation( "2.", nam ), Concatenation( "4_2.", nam ) ] );;
gap> names:= List( names, nam -> ReplacedString( nam, "23", "2*3" ) );;
gap> inputs2:= List( names, nam -> [ "4_2.L3(4).2_2*", "2.L3(4).2_2*",
>             Concatenation( "2.", nam ), Concatenation( "4_2.", nam ) ] );;
gap> inputs:= Concatenation( inputs1, inputs2 );
[ [ "4_2.L3(4).2_2", "2.L3(4).2_2", "2.L3(4).(2^2)_{123}",
    "4_2.L3(4).(2^2)_{123}" ],
  [ "4_2.L3(4).2_2", "2.L3(4).2_2", "2.L3(4).(2^2)_{1*23}",
    "4_2.L3(4).(2^2)_{1*23}" ],
  [ "4_2.L3(4).2_2", "2.L3(4).2_2", "2.L3(4).(2^2)_{123*}",
    "4_2.L3(4).(2^2)_{123*}" ],
  [ "4_2.L3(4).2_2", "2.L3(4).2_2", "2.L3(4).(2^2)_{1*23*}",
    "4_2.L3(4).(2^2)_{1*23*}" ],
  [ "4_2.L3(4).2_2*", "2.L3(4).2_2*", "2.L3(4).(2^2)_{12*3}",
    "4_2.L3(4).(2^2)_{12*3}" ],
  [ "4_2.L3(4).2_2*", "2.L3(4).2_2*", "2.L3(4).(2^2)_{1*2*3}",
    "4_2.L3(4).(2^2)_{1*2*3}" ],
  [ "4_2.L3(4).2_2*", "2.L3(4).2_2*", "2.L3(4).(2^2)_{12*3*}",
    "4_2.L3(4).(2^2)_{12*3*}" ],
  [ "4_2.L3(4).2_2*", "2.L3(4).2_2*", "2.L3(4).(2^2)_{1*2*3*}",
    "4_2.L3(4).(2^2)_{1*2*3*}" ] ]
gap> result2:= [];;
gap> for input in inputs do
>   tblMG := CharacterTable( input[1] );
>   tblG  := CharacterTable( input[2] );
>   tblGA := CharacterTable( input[3] );
>   name  := Concatenation( "new", input[4] );
>   lib   := CharacterTable( input[4] );
>   poss:= ConstructOrdinaryMGATable( tblMG, tblG, tblGA, name, lib );
>   Append( result2, poss );
> od;
#E 4 possibilities for new4_2.L3(4).(2^2)_{123}
#E no solution for new4_2.L3(4).(2^2)_{1*23}
#E no solution for new4_2.L3(4).(2^2)_{123*}
#E no solution for new4_2.L3(4).(2^2)_{1*23*}
#E 4 possibilities for new4_2.L3(4).(2^2)_{12*3}
#E no solution for new4_2.L3(4).(2^2)_{1*2*3}
#E no solution for new4_2.L3(4).(2^2)_{12*3*}
#E no solution for new4_2.L3(4).(2^2)_{1*2*3*}
gap> Length( result2 );
8
gap> result2:= List( result2, x -> x.table );
[ CharacterTable( "new4_2.L3(4).(2^2)_{123}" ),

```

```

CharacterTable( "new4_2.L3(4).(2^2)_{123}" ),
CharacterTable( "new4_2.L3(4).(2^2)_{123}" ),
CharacterTable( "new4_2.L3(4).(2^2)_{123}" ),
CharacterTable( "new4_2.L3(4).(2^2)_{12*3}" ),
CharacterTable( "new4_2.L3(4).(2^2)_{12*3}" ),
CharacterTable( "new4_2.L3(4).(2^2)_{12*3}" ),
CharacterTable( "new4_2.L3(4).(2^2)_{12*3}" ) ]
gap> List( result, t1 -> PositionsProperty( result2, t2 -> IsRecord(
> TransformingPermutationsCharacterTables( t1, t2 ) ) ) );
[ [ 1 ], [ 4 ], [ 7 ], [ 3 ], [ 6 ], [ 2 ], [ 5 ], [ 8 ] ]

```

The group $ON.2$ contains a maximal subgroup M of the type $4_2.L_3(4).2^2$, see [CCN⁺85, p. 132]. Only the third result table admits a class fusion into $ON.2$. This shows the existence of groups for the tables from the second orbit.

```

gap> on2:= CharacterTable( "ON.2" );;
gap> fus:= List( result, x -> PossibleClassFusions( x, on2 ) );;
gap> List( fus, Length );
[ 0, 0, 16, 0, 0, 0, 0, 0 ]

```

6.9 The Character Table of $\text{Aut}(L_2(81))$

The group $\text{Aut}(L_2(81)) \cong L_2(81).(2 \times 4)$ has the structure $G.2^2$ where $G = L_2(81).2_1$. Here we get two triples of possible actions on the tables of the groups $G.2_i$, and one possible character table for each triple.

```

gap> input:= [ "L2(81).2_1", "L2(81).4_1", "L2(81).4_2", "L2(81).2^2",
> "L2(81).(2x4)" ];;
gap> tblG := CharacterTable( input[1] );;
gap> tblsG2 := List( input{ [ 2 .. 4 ] }, CharacterTable );;
gap> name := Concatenation( "new", input[5] );;
gap> lib := CharacterTable( input[5] );;
gap> poss := ConstructOrdinaryGV4Table( tblG, tblsG2, name, lib );;
#I newL2(81).(2x4): 2 equivalence classes
gap> reps:= RepresentativesCharacterTables( poss );;
gap> Length( reps );
2

```

Due to the different underlying actions, the power maps of the two candidate tables differ.

```

gap> ord:= OrdersClassRepresentatives( reps[1].table );;
gap> ord = OrdersClassRepresentatives( reps[2].table );
true
gap> pos:= Position( ord, 80 );
33
gap> PowerMap( reps[1].table, 3 )[ pos ];
34
gap> PowerMap( reps[2].table, 3 )[ pos ];
33

```

$\text{Aut}(L_2(81))$ can be generated by $\text{PGL}(2, 81) = L_2(81).2_2$ and the Frobenius automorphism of order four that is defined on $GL(2, 81)$ as the map that cubes the matrix entries. The elements of order 80 in $\text{Aut}(L_2(81))$ are conjugates of diagonal matrices modulo scalar matrices, which are mapped to their third powers by the Frobenius homomorphism. So the third power map of $\text{Aut}(L_2(81))$ fixes the classes of elements of order 80. In other words, the second of the two tables is the right one.

```

gap> trans:= TransformingPermutationsCharacterTables( reps[2].table, lib );;
gap> IsRecord( trans );
true
gap> List( reps[2].G2fusGV4, x -> OnTuples( x, trans.columns ) )
> = List( tblsG2, x -> GetFusionMap( x, lib ) );
true
gap> ConstructModularGV4Tables( tblG, tblsG2, poss, lib );;
#I not all input tables for L2(81).(2x4) mod 3 available
#I not all input tables for L2(81).(2x4) mod 5 available
#I not all input tables for L2(81).(2x4) mod 41 available

```

6.10 The Character Table of $O_8^+(3).2_{111}^2$

The construction of the character table of the group $O_8^+(3).2_{111}^2$ is not as straightforward as the constructions shown in Section 6.2. Here we get 26 triples of actions on the tables of the three subgroups $G.2_i$ of index two, but only one of them leads to candidates for the desired character table. Specifically, we get 64 such candidates, in two equivalence classes w.r.t. permutation equivalence.

```

gap> input:= [ "08+(3)", "08+(3).2_1", "08+(3).2_1'", "08+(3).2_1''",
> "08+(3).(2^2)_{111}" ];;
gap> tblG := CharacterTable( input[1] );;
gap> tblsG2 := List( input{ [ 2 .. 4 ] }, CharacterTable );;
gap> name := Concatenation( "new", input[5] );;
gap> lib := CharacterTable( input[5] );;
gap> poss := ConstructOrdinaryGV4Table( tblG, tblsG2, name, lib );;
#I new08+(3).(2^2)_{111}: 2 equivalence classes
gap> Length( poss );
64
gap> reps:= RepresentativesCharacterTables( poss );;
gap> Length( reps );
2

```

The two candidate tables differ only in four irreducible characters involving irrationalities on the classes of element order 28. All three subgroups $G.2_i$ contain elements of order 28 that do not lie in the simple group G ; these classes are roots of the same (unique) class of element order 7. The centralizer C of an order 7 element in $G.2^2$ has order $112 = 2^4 \cdot 7$, the intersection of C with G has the structure $2^2 \times 7$ since G contains three classes of cyclic subgroups of the order 14, and each of the intersections of C with one of the subgroups $G.2_i$ has the structure $2 \times 4 \times 7$, so the structure of C is $4^2 \times 7 \cong 4 \times 28$.

```

gap> t:= reps[1].table;;
gap> ord7:= Filtered( [ 1 .. NrConjugacyClasses( t ) ],
> i -> OrdersClassRepresentatives( t )[i] = 7 );
[ 37 ]
gap> SizesCentralizers( t ){ ord7 };
[ 112 ]
gap> ord28:= Filtered( [ 1 .. NrConjugacyClasses( t ) ],
> i -> OrdersClassRepresentatives( t )[i] = 28 );
[ 112, 113, 114, 115, 161, 162, 163, 164, 210, 211, 212, 213 ]
gap> List( reps[1].G2fusGV4, x -> Intersection( ord28, x ) );
[ [ 112, 113, 114, 115 ], [ 161, 162, 163, 164 ], [ 210, 211, 212, 213 ] ]
gap> sub:= CharacterTable( "Cyclic", 28 ) * CharacterTable( "Cyclic", 4 );;
gap> List( reps, x -> Length( PossibleClassFusions( sub, x.table ) ) );
[ 0, 96 ]

```

It turns out that only one of the two candidate tables admits a class fusion from the character table of C , thus we have determined the ordinary character table of $O_8^+(3).2_{111}^2$.

```
gap> trans:= TransformingPermutationsCharacterTables( reps[2].table, lib );;
gap> IsRecord( trans );
true
gap> List( reps[2].G2fusGV4, x -> OnTuples( x, trans.columns ) )
> = List( tblsG2, x -> GetFusionMap( x, lib ) );
true
gap> ConstructModularGV4Tables( tblG, tblsG2, poss, lib );;
#I not all input tables for 08+(3).(2^2)_{111} mod 3 available
```

So also the p -modular tables of $O_8^+(3).2_{111}^2$ can be computed this way, provided that the p -modular tables of the index 2 subgroups are available.

7 Examples for the Type $2^2.G$

We compute the character table of a group of the type $2^2.G$ from the character tables of the three factor groups of the type $2.G$, using the function `PossibleCharacterTablesOfTypeV4G`, see Section 3.4.

7.1 The Character Table of $2^2.Sz(8)$

The three central involutions in $2^2.Sz(8)$ are permuted cyclicly by an outer automorphism α of order three. In order to apply `PossibleCharacterTablesOfTypeV4G`, we need the character table of the group $2.Sz(8)$ and the action on the classes of $Sz(8)$ that is induced by α .

The ordinary character table of $G = Sz(8)$ admits exactly five table automorphisms of order dividing 3. Each of these possibilities leads to exactly one possible character table of $2^2.G$, and the five tables are permutation equivalent. From this point of view, we need not know which of the table automorphisms are induced by outer *group* automorphisms of G .

```
gap> t:= CharacterTable( "Sz(8)" );;
gap> 2t:= CharacterTable( "2.Sz(8)" );;
gap> aut:= AutomorphismsOfTable( t );;
gap> elms:= Set( List( Filtered( aut, x -> Order( x ) in [ 1, 3 ] ),
> SmallestGeneratorPerm ) );
[ (), (9,10,11), (6,7,8), (6,7,8)(9,10,11), (6,7,8)(9,11,10) ]
gap> poss:= List( elms,
> pi -> PossibleCharacterTablesOfTypeV4G( t, 2t, pi, "2^2.Sz(8)" ) );
[ [ CharacterTable( "2^2.Sz(8)" ) ], [ CharacterTable( "2^2.Sz(8)" ) ],
[ CharacterTable( "2^2.Sz(8)" ) ], [ CharacterTable( "2^2.Sz(8)" ) ],
[ CharacterTable( "2^2.Sz(8)" ) ] ]
gap> reps:= RepresentativesCharacterTables( Concatenation( poss ) );
[ CharacterTable( "2^2.Sz(8)" ) ]
```

The tables coincide with the one that is stored in the GAP library.

```
gap> IsRecord( TransformingPermutationsCharacterTables( reps[1],
> CharacterTable( "2^2.Sz(8)" ) ) );
true
```

The computation of the p -modular character table of $2^2.G$ from the p -modular character table of $2.G$ and the three factor fusions from $2^2.G$ to $2.G$ is straightforward, as is stated in Section 3.4. The three fusions are stored on the tables returned by `PossibleCharacterTablesOfTypeV4G`.

```

gap> GetFusionMap( poss[1][1], 2t, "1" );
[ 1, 1, 2, 2, 3, 4, 5, 6, 6, 7, 7, 8, 8, 9, 9, 10, 10, 11, 11, 12, 12, 13,
  13, 14, 14, 15, 15, 16, 16, 17, 17, 18, 18, 19, 19 ]
gap> GetFusionMap( poss[1][1], 2t, "2" );
[ 1, 2, 1, 2, 3, 4, 5, 6, 7, 6, 7, 8, 9, 8, 9, 10, 11, 10, 11, 12, 13, 12,
  13, 14, 15, 14, 15, 16, 17, 16, 17, 18, 19, 18, 19 ]
gap> GetFusionMap( poss[1][1], 2t, "3" );
[ 1, 2, 2, 1, 3, 4, 5, 6, 7, 7, 6, 8, 9, 9, 8, 10, 11, 11, 10, 12, 13, 13,
  12, 14, 15, 15, 14, 16, 17, 17, 16, 18, 19, 19, 18 ]

```

The GAP library function `BrauerTableOfTypeV4G` can be used to derive Brauer tables of $2^2.G$. We have to compute the p -modular tables for prime divisors p of $|G|$, that is, for $p \in \{2, 5, 7, 13\}$.

```

gap> Set( Factors( Size( t ) ) );
[ 2, 5, 7, 13 ]

```

Clearly $p = 2$ is uninteresting from this point of view because the 2-modular table of $2^2.G$ can be identified with the 2-modular table of G .

For each of the five ordinary tables (corresponding to the five possible table automorphisms of G) constructed above, we get one candidate of a 5-modular table. However, these tables are **not** all equivalent. There are two equivalence classes, and one of the two possibilities is inconsistent in the sense that not all tensor products of irreducibles decompose into irreducibles.

```

gap> cand:= List( poss, 1 -> BrauerTableOfTypeV4G( l[1], 2t mod 5,
> ConstructionInfoCharacterTable( l[1] )[3] ) );
[ BrauerTable( "2^2.Sz(8)", 5 ), BrauerTable( "2^2.Sz(8)", 5 ),
  BrauerTable( "2^2.Sz(8)", 5 ), BrauerTable( "2^2.Sz(8)", 5 ),
  BrauerTable( "2^2.Sz(8)", 5 ) ]
gap> Length( RepresentativesCharacterTables( cand ) );
2
gap> List( cand, CTblLib.Test.TensorDecomposition );
[ false, true, false, true, true ]
gap> Length( RepresentativesCharacterTables( cand{ [ 2, 4, 5 ] } ) );
1
gap> IsRecord( TransformingPermutationsCharacterTables( cand[2],
> CharacterTable( "2^2.Sz(8)" ) mod 5 ) );
true

```

This implies that only those table automorphisms of G can be induced by an outer group automorphism that move the classes of element order 13.

The 7-modular table of $2^2.G$ is uniquely determined, independent of the choice of the table automorphism of G .

```

gap> cand:= List( poss, 1 -> BrauerTableOfTypeV4G( l[1], 2t mod 7,
> ConstructionInfoCharacterTable( l[1] )[3] ) );
[ BrauerTable( "2^2.Sz(8)", 7 ), BrauerTable( "2^2.Sz(8)", 7 ),
  BrauerTable( "2^2.Sz(8)", 7 ), BrauerTable( "2^2.Sz(8)", 7 ),
  BrauerTable( "2^2.Sz(8)", 7 ) ]
gap> Length( RepresentativesCharacterTables( cand ) );
1
gap> IsRecord( TransformingPermutationsCharacterTables( cand[1],
> CharacterTable( "2^2.Sz(8)" ) mod 7 ) );
true

```

We get two candidates for the 13-modular table of $2^2.G$, also if we consider only the three admissible table automorphisms.

```

gap> elms:= elms{ [ 2, 4, 5 ] };
[ (9,10,11), (6,7,8)(9,10,11), (6,7,8)(9,11,10) ]
gap> poss:= poss{ [ 2, 4, 5 ] };;
gap> cand:= List( poss, 1 -> BrauerTableOfTypeV4G( 1[1], 2t mod 13,
>      ConstructionInfoCharacterTable( 1[1] ) [3] ) );
[ BrauerTable( "2^2.Sz(8)", 13 ), BrauerTable( "2^2.Sz(8)", 13 ),
  BrauerTable( "2^2.Sz(8)", 13 ) ]
gap> Length( RepresentativesCharacterTables( cand ) );
2
gap> List( cand, CTblLib.Test.TensorDecomposition );
[ true, true, true ]

```

The action of the outer automorphism of order three of G can be read off from the 2-modular table of G . Note that the ordinary and the 5-modular character table of G possess two independent table automorphisms of order three, whereas the group of table automorphisms of the 2-modular table has order three. (The reason is that the irrational values on the classes of the element orders 7 and 13 appear in the same irreducible 2-modular Brauer characters.)

```

gap> mod2:= CharacterTable( "Sz(8)" ) mod 2;
BrauerTable( "Sz(8)", 2 )
gap> AutomorphismsOfTable( mod2 );
Group([ (3,4,5)(6,7,8) ])
gap> OrdersClassRepresentatives( mod2 );
[ 1, 5, 7, 7, 7, 13, 13, 13 ]

```

This means that the first candidate is ruled out; this determines the 13-modular character table of $2^2.G$.

```

gap> Length( RepresentativesCharacterTables( cand{ [ 2, 3 ] } ) );
1
gap> IsRecord( TransformingPermutationsCharacterTables( cand[2],
>      CharacterTable( "2^2.Sz(8)" ) mod 13 ) );
true

```

7.2 Atlas Tables of the Type $2^2.G$ (September 2005)

Besides $2^2.Sz(8)$ (cf. Section 7.1), $2^2.O_8^+(3)$ (cf. Section 7.3), and certain central extensions of $L_3(4)$ (cf. Section 7.4), the following examples of central extensions of nearly simple ATLAS groups G by a Klein four group occur.

```

gap> listV4G:= [
> [ "2^2.L3(4)", "2.L3(4)", "L3(4)" ],
> [ "2^2.L3(4).2_1", "2.L3(4).2_1", "L3(4).2_1" ],
> [ "(2^2x3).L3(4)", "6.L3(4)", "3.L3(4)" ],
> [ "(2^2x3).L3(4).2_1", "6.L3(4).2_1", "3.L3(4).2_1" ],
> [ "2^2.O8+(2)", "2.O8+(2)", "O8+(2)" ],
> [ "2^2.U6(2)", "2.U6(2)", "U6(2)" ],
> [ "(2^2x3).U6(2)", "6.U6(2)", "3.U6(2)" ],
> [ "2^2.2E6(2)", "2.2E6(2)", "2E6(2)" ],
> [ "(2^2x3).2E6(2)", "6.2E6(2)", "3.2E6(2)" ],
> ];;

```

(For the tables of $(2^2 \times 3).G$, with G one of $L_3(4)$, $U_6(2)$, or ${}^2E_6(2)$, we could alternatively use the tables of $2^2.G$ and $3.G$, and the construction described in [Bre].)

The function for computing the candidates for the ordinary character tables is similar to the one from Section 6.2.

```

gap> ConstructOrdinaryV4GTable:= function( tblG, tbl2G, name, lib )
>   local ord3, nam, poss, reps, trans;
>
>   # Compute the possible actions for the ordinary tables.
>   ord3:= Set( List( Filtered( AutomorphismsOfTable( tblG ),
>                             x -> Order( x ) = 3 ),
>               SmallestGeneratorPerm ) );
>   if 1 < Length( ord3 ) then
>     Print( "#I ", name,
>           ": the action of the automorphism is not unique" );
>   fi;
>   # Compute the possible ordinary tables for the given actions.
>   nam:= Concatenation( "new", name );
>   poss:= Concatenation( List( ord3, pi ->
>     PossibleCharacterTablesOfTypeV4G( tblG, tbl2G, pi, nam ) ) );
>   # Test the possibilities for permutation equivalence.
>   reps:= RepresentativesCharacterTables( poss );
>   if 1 < Length( reps ) then
>     Print( "#I ", name, ": ", Length( reps ),
>           " equivalence classes\n" );
>   elif Length( reps ) = 0 then
>     Print( "#E ", name, ": no solution\n" );
>   else
>     # Compare the computed table with the library table.
>     if not IsCharacterTable( lib ) then
>       Print( "#I no library table for ", name, "\n" );
>       PrintToLib( name, poss[1].table );
>     else
>       trans:= TransformingPermutationsCharacterTables( reps[1], lib );
>       if not IsRecord( trans ) then
>         Print( "#E computed table and library table for ", name,
>               " differ\n" );
>       fi;
>     fi;
>   fi;
>   return poss;
> end;;

```

Concerning the Brauer tables, the same ambiguity problem may occur as in Section 6.2: Some candidates for the ordinary table may be excluded due to information provided by some p -modular table, see Section 7.1 for an easy example. Our strategy is analogous to the one used in Section 6.2.

```

gap> ConstructModularV4GTables:= function( tblG, tbl2G, ordposs,
>                                         ordlibtblV4G )
>   local name, modposs, primes, checkordinary, i, p, tmodp, 2tmodp, aut,
>         poss, modlib, trans, reps;
>
>   if not IsCharacterTable( ordlibtblV4G ) then
>     Print( "#I no ordinary library table ... \n" );
>     return [];
>   fi;
>   name:= Identifier( ordlibtblV4G );
>   modposs:= [];
>   primes:= Set( Factors( Size( tblG ) ) );
>   ordposs:= ShallowCopy( ordposs );

```

```

> checkordinary:= false;
> for i in [ 1 .. Length( ordposs ) ] do
>   modposs[i]:= [];
>   for p in primes do
>     tmodp := tblG mod p;
>     2tmodp:= tbl2G mod p;
>     if IsCharacterTable( tmodp ) and IsCharacterTable( 2tmodp ) then
>       aut:= ConstructionInfoCharacterTable( ordposs[i] )[3];
>       poss:= BrauerTableOfTypeV4G( ordposs[i], 2tmodp, aut );
>       if CTblLib.Test.TensorDecomposition( poss, false ) = false then
>         Print( "#I excluded cand. ", i, " (out of ",
>           Length( ordposs ), ") for ", name, " by ", p,
>           "-mod. table\n" );
>         Unbind( ordposs[i] );
>         Unbind( modposs[i] );
>         checkordinary:= true;
>         break;
>       fi;
>       Add( modposs[i], poss );
>     else
>       Print( "#I not all input tables for ", name, " mod ", p,
>         " available\n" );
>       primes:= Difference( primes, [ p ] );
>     fi;
>   od;
>   if IsBound( modposs[i] ) then
>     # Compare the computed Brauer tables with the library tables.
>     for poss in modposs[i] do
>       p:= UnderlyingCharacteristic( poss );
>       modlib:= ordlibtblV4G mod p;
>       if IsCharacterTable( modlib ) then
>         trans:= TransformingPermutationsCharacterTables(
>           poss, modlib );
>         if not IsRecord( trans ) then
>           Print( "#E computed table and library table for ",
>             name, " mod ", p, " differ\n" );
>         fi;
>       else
>         Print( "#I no library table for ",
>           name, " mod ", p, "\n" );
>         PrintToLib( name, poss );
>       fi;
>     od;
>   fi;
> od;
> if checkordinary then
>   # Test whether the ordinary table is admissible.
>   ordposs:= Compacted( ordposs );
>   modposs:= Compacted( modposs );
>   reps:= RepresentativesCharacterTables( ordposs );
>   if 1 < Length( reps ) then
>     Print( "#I ", name, ": ", Length( reps ),
>       " equivalence classes (ord. table)\n" );
>   elif Length( reps ) = 0 then

```

```

>     Print( "#E ", name, ": no solution (ord. table)\n" );
>   else
>     # Compare the computed table with the library table.
>     trans:= TransformingPermutationsCharacterTables( reps[1],
>       ordlibtblV4G );
>     if not IsRecord( trans ) then
>       Print( "#E computed table and library table for ", name,
>         " differ\n" );
>     fi;
>   fi;
>   # Test the uniqueness of the Brauer tables.
>   for poss in TransposedMat( modposs ) do
>     reps:= RepresentativesCharacterTables( poss );
>     if Length( reps ) <> 1 then
>       Print( "#I ", name, ": ", Length( reps ), " candidates for the ",
>         UnderlyingCharacteristic( reps[1] ), "-modular table\n" );
>     fi;
>   od;
>   return rec( ordinary:= ordposs, modular:= modposs );
> end;;

```

In our examples, the action of the outer automorphism of order three on the classes of G turns out to be uniquely determined by the table automorphisms of the character table of G .

```

gap> for input in listV4G do
>   tblG := CharacterTable( input[3] );
>   tbl2G := CharacterTable( input[2] );
>   lib := CharacterTable( input[1] );
>   poss := ConstructOrdinaryV4GTable( tblG, tbl2G, input[1], lib );
>   ConstructModularV4GTables( tblG, tbl2G, poss, lib );
>   od;
#I excluded cand. 1 (out of 16) for 2^2.L3(4).2_1 by 7-mod. table
#I excluded cand. 2 (out of 16) for 2^2.L3(4).2_1 by 7-mod. table
#I excluded cand. 7 (out of 16) for 2^2.L3(4).2_1 by 7-mod. table
#I excluded cand. 10 (out of 16) for 2^2.L3(4).2_1 by 7-mod. table
#I excluded cand. 15 (out of 16) for 2^2.L3(4).2_1 by 7-mod. table
#I excluded cand. 16 (out of 16) for 2^2.L3(4).2_1 by 7-mod. table
#I excluded cand. 1 (out of 16) for (2^2x3).L3(4).2_1 by 7-mod. table
#I excluded cand. 2 (out of 16) for (2^2x3).L3(4).2_1 by 7-mod. table
#I excluded cand. 7 (out of 16) for (2^2x3).L3(4).2_1 by 7-mod. table
#I excluded cand. 10 (out of 16) for (2^2x3).L3(4).2_1 by 7-mod. table
#I excluded cand. 15 (out of 16) for (2^2x3).L3(4).2_1 by 7-mod. table
#I excluded cand. 16 (out of 16) for (2^2x3).L3(4).2_1 by 7-mod. table
#I not all input tables for 2^2.2E6(2) mod 2 available
#I not all input tables for 2^2.2E6(2) mod 3 available
#I not all input tables for 2^2.2E6(2) mod 5 available
#I not all input tables for 2^2.2E6(2) mod 7 available
#I not all input tables for (2^2x3).2E6(2) mod 2 available
#I not all input tables for (2^2x3).2E6(2) mod 3 available
#I not all input tables for (2^2x3).2E6(2) mod 5 available
#I not all input tables for (2^2x3).2E6(2) mod 7 available
#I not all input tables for (2^2x3).2E6(2) mod 11 available
#I not all input tables for (2^2x3).2E6(2) mod 13 available
#I not all input tables for (2^2x3).2E6(2) mod 17 available

```

```
#I not all input tables for (2^2x3).2E6(2) mod 19 available
```

7.3 The Character Table of $2^2.O_8^+(3)$ (March 2009)

When one tries to construct the character table of the central extensions of $G = O_8^+(3)$ by a Klein four group, in the same way as in Section 7.2, one notices that the order three automorphism that relates the three central extensions of G by an involution is *not* uniquely determined.

```
gap> entry:= [ "2^2.08+(3)", "2.08+(3)", "08+(3)" ];;
gap> tblG:= CharacterTable( entry[3] );;
gap> aut:= AutomorphismsOfTable( tblG );;
gap> ord3:= Set( List( Filtered( aut, x -> Order( x ) = 3 ),
> SmallestGeneratorPerm ) );;
gap> Length( ord3 );
4
```

However, the table candidates one gets from the four possible automorphisms turn out to be all equivalent, hence the character table of $2^2.O_8^+(3)$ can be constructed as follows.

```
gap> poss:= [];;
gap> tbl2G:= CharacterTable( entry[2] );
CharacterTable( "2.08+(3)" )
gap> for pi in ord3 do
> Append( poss,
> PossibleCharacterTablesOfTypeV4G( tblG, tbl2G, pi, entry[1] ) );
> od;
gap> Length( poss );
32
gap> poss:= RepresentativesCharacterTables( poss );;
gap> Length( poss );
1
```

The computed table coincides with the library table.

```
gap> lib:= CharacterTable( entry[1] );;
gap> if TransformingPermutationsCharacterTables( poss[1], lib ) = fail then
> Print( "#E differences for ", entry[1], "\n" );
> fi;
```

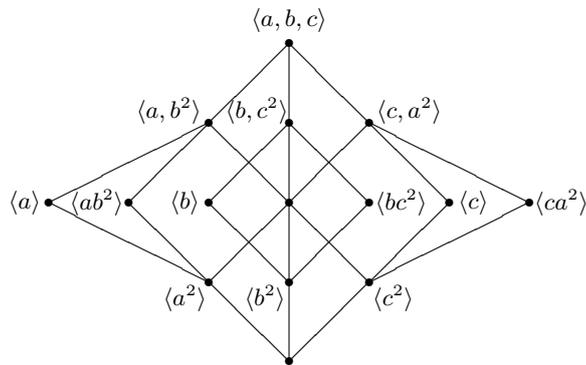
7.4 The Character Table of the Schur Cover of $L_3(4)$ (September 2005)

The Schur cover of $G = L_3(4)$ has the structure $(4^2 \times 3).L_3(4)$. Following [CCN⁺85, p. 23], we regard the multiplier of G as

$$M = \langle a, b, c, d \mid [a, b] = [a, c] = [a, d] = [b, c] = [b, d] = [c, d] = a^4 = b^4 = c^4 = d^3 = abc \rangle,$$

and we will consider the automorphism α of $M.G$ that acts as $(a, b, c)(d)$ on M .

The subgroup lattice of the subgroup $\langle a, b, c \rangle = \langle a, b \rangle \cong 4^2$ of M looks as follows. (The subgroup in the centre of the picture is the Klein four group $\langle a^2, b^2, c^2 \rangle = \langle a^2, b^2 \rangle$.)



(The symmetry w.r.t. α would be reflected better in a three dimensional model, with $\langle a, b \rangle$, $\langle a^2, b^2 \rangle$, and the trivial subgroup on a vertical symmetry axis, and with the remaining subgroups on three circles such that α induces a rotation.)

We have $(M/\langle a \rangle).G \cong (M/\langle b \rangle).G \cong (M/\langle c \rangle).G \cong 12_2.G$ and $(M/\langle ab^2 \rangle).G \cong (M/\langle bc^2 \rangle).G \cong (M/\langle ca^2 \rangle).G \cong 12_1.G$. This is because the action of $G.2_2$ fixes a , and swaps b and c ; so b is inverted modulo $\langle a \rangle$ but fixed modulo $\langle ab^2 \rangle$, and the normal subgroup of order four in $4_2.G.2_2$ is central but that in $4_1.G.2_2$ is not central.

The constructions of the character tables of $4^2.G$ and $(4^2 \times 3).G$ are essentially the same. We start with the table of $4^2.G$. It can be regarded as a central extension $H = V.2^2.G$ of $2^2.G$ by a Klein four group V . The three subgroups of order two in V are cyclicly permuted by the automorphism of $M/\langle d \rangle$ induced by α , so the three factors by these subgroups are isomorphic groups F , say, with the structure $(2 \times 4).G$.

The group F itself is a central extension of $2.G$ by a Klein four group, but in this case the three factor groups by the order two subgroups of the Klein four group are nonisomorphic groups, of the types $4_1.G$, $4_2.G$, and $2^2.G$, respectively. The GAP function `PossibleCharacterTablesOfTypeV4G` can be used to construct the character table of F from the three factors. Note that in this case, no information about table automorphisms is required.

```
gap> tblG:= CharacterTable( "2.L3(4)" );;
gap> tbls2G:= List( [ "4_1.L3(4)", "4_2.L3(4)", "2^2.L3(4)" ],
> CharacterTable );;
gap> poss:= PossibleCharacterTablesOfTypeV4G( tblG, tbls2G, "(2x4).L3(4)" );;
gap> Length( poss );
2
gap> reps:= RepresentativesCharacterTables( poss );
[ CharacterTable( "(2x4).L3(4)" ) ]
gap> lib:= CharacterTable( "(2x4).L3(4)" );;
gap> IsRecord( TransformingPermutationsCharacterTables( reps[1], lib ) );
true
```

In the second step, we construct the table of $4^2.G$ from that of $(2 \times 4).G$ and the table automorphism of $2^2.G$ that is induced by α ; it turns out that the group of table automorphisms of $2^2.G$ contains a unique subgroup of order three.

```
gap> tblG:= tbls2G[3];
CharacterTable( "2^2.L3(4)" )
gap> tbl2G:= lib;
CharacterTable( "(2x4).L3(4)" )
gap> aut:= AutomorphismsOfTable( tblG );;
gap> ord3:= Set( List( Filtered( aut, x -> Order( x ) = 3 ),
> SmallestGeneratorPerm ) );
```

```

[ (2,3,4)(6,7,8)(10,11,12)(13,15,17)(14,16,18)(20,21,22)(24,25,26)(28,29,
  30)(32,33,34) ]
gap> pi:= ord3[1];;
gap> poss:= PossibleCharacterTablesOfTypeV4G( tblG, tbl2G, pi, "4^2.L3(4)" );;
gap> Length( poss );
4
gap> reps:= RepresentativesCharacterTables( poss );
[ CharacterTable( "4^2.L3(4)" ) ]
gap> lib:= CharacterTable( "4^2.L3(4)" );;
gap> IsRecord( TransformingPermutationsCharacterTables( reps[1], lib ) );
true

```

With the same approach, we compute the table of $(2 \times 12).G = 2^2.6.G$ from the tables of the three nonisomorphic factor groups $12_1.G$, $12_2.G$, and $(2^2 \times 3).G$, and we compute the table of $(4^2 \times 3).G = 2^2.(2^2 \times 3).G$ from the three tables of the factor groups $(2 \times 12).G$ and the action induced by α .

```

gap> tblG:= CharacterTable( "6.L3(4)" );;
gap> tbls2G:= List( [ "12_1.L3(4)", "12_2.L3(4)", "(2^2x3).L3(4)",
> CharacterTable );;
gap> poss:= PossibleCharacterTablesOfTypeV4G( tblG, tbls2G, "(2x12).L3(4)" );;
gap> Length( poss );
2
gap> reps:= RepresentativesCharacterTables( poss );
[ CharacterTable( "(2x12).L3(4)" ) ]
gap> lib:= CharacterTable( "(2x12).L3(4)" );;
gap> IsRecord( TransformingPermutationsCharacterTables( reps[1], lib ) );
true
gap> tblG:= CharacterTable( "(2^2x3).L3(4)" );;
CharacterTable( "(2^2x3).L3(4)" )
gap> tbl2G:= CharacterTable( "(2x12).L3(4)" );;
CharacterTable( "(2x12).L3(4)" )
gap> aut:= AutomorphismsOfTable( tblG );;
gap> ord3:= Set( List( Filtered( aut, x -> Order( x ) = 3 ),
> SmallestGeneratorPerm ) );
[ (2,7,8)(3,4,10)(6,11,12)(14,19,20)(15,16,22)(18,23,24)(26,27,28)(29,35,
  41)(30,37,43)(31,39,45)(32,36,42)(33,38,44)(34,40,46)(48,53,54)(49,50,
  56)(52,57,58)(60,65,66)(61,62,68)(64,69,70)(72,77,78)(73,74,80)(76,81,
  82)(84,89,90)(85,86,92)(88,93,94) ]
gap> pi:= ord3[1];;
gap> poss:= PossibleCharacterTablesOfTypeV4G( tblG, tbl2G, pi,
> "(4^2x3).L3(4)" );;
gap> Length( poss );
4
gap> reps:= RepresentativesCharacterTables( poss );
[ CharacterTable( "(4^2x3).L3(4)" ) ]
gap> lib:= CharacterTable( "(4^2x3).L3(4)" );;
gap> IsRecord( TransformingPermutationsCharacterTables( reps[1], lib ) );
true

```

8 Examples of Extensions by p -singular Automorphisms

8.1 Some p -Modular Tables of Groups of the Type $M.G.A$

We show an alternative construction of p -modular tables of certain groups that have been met in Section 4.3. Each entry in the GAP list `listMGA` contains the `Identifier` values of character tables of groups of the types $M.G$, G , $G.A$, and $M.G.A$. For each entry with $|A| = p$, a prime integer, we fetch the p -modular table of G and the ordinary table of $G.A$, compute the action of $G.A$ on the p -regular classes of G , and then compute the p -modular table of $G.A$. Analogously, we compute the p -modular table of $M.G.A$ from the p -modular table of $M.G$ and the ordinary table of $M.G.A$.

```
gap> for input in listMGA do
>   ordtblMG := CharacterTable( input[1] );
>   ordtblG := CharacterTable( input[2] );
>   ordtblGA := CharacterTable( input[3] );
>   ordtblMGA := CharacterTable( input[4] );
>   p:= Size( ordtblGA ) / Size( ordtblG );
>   if IsPrimeInt( p ) then
>     modtblG:= ordtblG mod p;
>     if modtblG <> fail then
>       modtblGA := CharacterTableRegular( ordtblGA, p );
>       SetIrr( modtblGA, IBrOfExtensionBySingularAutomorphism( modtblG,
>         ordtblGA ) );
>       if TransformingPermutationsCharacterTables( modtblGA,
>         ordtblGA mod p ) = fail then
>         Print( "#E computed table and library table for ", input[3],
>           " mod ", p, " differ\n" );
>       fi;
>     fi;
>     modtblMG:= ordtblMG mod p;
>     if modtblMG <> fail then
>       modtblMGA := CharacterTableRegular( ordtblMGA, p );
>       SetIrr( modtblMGA, IBrOfExtensionBySingularAutomorphism( modtblMG,
>         ordtblMGA ) );
>       if TransformingPermutationsCharacterTables( modtblMGA,
>         ordtblMGA mod p ) = fail then
>         Print( "#E computed table and library table for ", input[4],
>           " mod ", p, " differ\n" );
>       fi;
>     fi;
>   fi;
> od;
```

8.2 Some p -Modular Tables of Groups of the Type $G.S_3$

We show an alternative construction of 2- and 3-modular tables of certain groups that have been met in Section 5.2. Each entry in the GAP list `listGS3` contains the `Identifier` values of character tables of groups of the types G , $G.2$, $G.3$, and $G.S_3$. For each entry, we fetch the 2-modular table of G and the ordinary table of $G.2$, compute the action of $G.2$ on the 2-regular classes of G , and then compute the 2-modular table of $G.2$. Analogously, we compute the 3-modular table of $G.3$ from the 3-modular table of G and the ordinary table of $G.3$, and we compute the 2-modular table of $G.S_3$ from the 2-modular table of $G.3$ and the ordinary table of $G.S_3$.

```
gap> for input in listGS3 do
```

```

> modtblG:= CharacterTable( input[1] ) mod 2;
> if modtblG <> fail then
>   ordtblG2 := CharacterTable( input[2] );
>   modtblG2 := CharacterTableRegular( ordtblG2, 2 );
>   SetIrr( modtblG2, IBrOfExtensionBySingularAutomorphism( modtblG,
>     ordtblG2 ) );
>   if TransformingPermutationsCharacterTables( modtblG2,
>     ordtblG2 mod 2 ) = fail then
>     Print( "#E computed table and library table for ", input[2],
>       " mod 2 differ\n" );
>   fi;
> fi;
> modtblG:= CharacterTable( input[1] ) mod 3;
> if modtblG <> fail then
>   ordtblG3 := CharacterTable( input[3] );
>   modtblG3 := CharacterTableRegular( ordtblG3, 3 );
>   SetIrr( modtblG3, IBrOfExtensionBySingularAutomorphism( modtblG,
>     ordtblG3 ) );
>   if TransformingPermutationsCharacterTables( modtblG3,
>     ordtblG3 mod 3 ) = fail then
>     Print( "#E computed table and library table for ", input[3],
>       " mod 3 differ\n" );
>   fi;
> fi;
> modtblG3:= CharacterTable( input[3] ) mod 2;
> if modtblG3 <> fail then
>   ordtblGS3 := CharacterTable( input[4] );
>   modtblGS3 := CharacterTableRegular( ordtblGS3, 2 );
>   SetIrr( modtblGS3, IBrOfExtensionBySingularAutomorphism( modtblG3,
>     ordtblGS3 ) );
>   if TransformingPermutationsCharacterTables( modtblGS3,
>     ordtblGS3 mod 2 ) = fail then
>     Print( "#E computed table and library table for ", input[4],
>       " mod 2 differ\n" );
>   fi;
> fi;
> od;

```

8.3 2-Modular Tables of Groups of the Type $G.2^2$

We show an alternative construction of 2-modular tables of certain groups that have been met in Section 6.2. Each entry in the GAP list `listGV4` contains the `Identifier` values of character tables of groups of the types G , $G.2_1$, $G.2_2$, $G.2_3$, and $G.2^2$. For each entry, we fetch the 2-modular table of G and the ordinary tables of the groups $G.2_i$, and compute the 2-modular tables of $G.2_i$; Then we compute from this modular table and the ordinary table of $G.2^2$ the 2-modular table of $G.2^2$.

```

gap> for input in listGV4 do
>   modtblG := CharacterTable( input[1] ) mod 2;
>   if modtblG <> fail then
>     ordtblsG2 := List( input{ [ 2 .. 4 ] }, CharacterTable );
>     ordtblGV4 := CharacterTable( input[5] );
>     for tblG2 in ordtblsG2 do
>       modtblG2:= CharacterTableRegular( tblG2, 2 );
>       SetIrr( modtblG2, IBrOfExtensionBySingularAutomorphism( modtblG,

```

```

>
>         tblG2 ) );
>   if TransformingPermutationsCharacterTables( modtblG2,
>         tblG2 mod 2 ) = fail then
>     Print( "#E computed table and library table for ",
>           Identifier( tblG2 ), " mod 2 differ\n" );
>   fi;
>   modtblGV4:= CharacterTableRegular( ordtblGV4, 2 );
>   SetIrr( modtblGV4, IBrOfExtensionBySingularAutomorphism( modtblG2,
>         ordtblGV4 ) );
>   if TransformingPermutationsCharacterTables( modtblGV4,
>         ordtblGV4 mod 2 ) = fail then
>     Print( "#E computed table and library table for ", input[5],
>           " mod 2 differ\n" );
>   fi;
> od;
> fi;
> od;

```

9 Examples of Subdirect Products of Index Two

Typical examples of this construction are those maximal subgroups of alternating groups A_n that extend in the corresponding symmetric groups S_n to direct products of the structures $S_m \times S_{n-m}$, for $2 < m < n/2$. Also certain subgroups of these maximal subgroups that have this structure can be interesting, see Section 4.2.

9.1 Certain Dihedral Groups as Subdirect Products of Index Two

Also dihedral groups of order $2n$ with n divisible by at least two different primes have the required structure: Let $n = n_1 n_2$ with coprime n_1, n_2 , and let the normal subgroups H_1, H_2 be cyclic subgroups of order n_1 and n_2 , respectively, inside the cyclic subgroup of index two. Then the factors $G/N_1, G/N_2$ are themselves dihedral groups.

So an example (with $n_1 = 3$ and $n_2 = 5$) is the construction of the dihedral group D_{30} as a subdirect product of index two in the direct product $D_6 \times D_{10}$.

```

gap> tblh1:= CharacterTable( "C3" );;
gap> tblg1:= CharacterTable( "S3" );;
gap> StoreFusion( tblh1, PossibleClassFusions( tblh1, tblg1 )[1], tblg1 );
gap> tblh2:= CharacterTable( "C5" );;
gap> tblg2:= CharacterTable( "D10" );;
gap> StoreFusion( tblh2, PossibleClassFusions( tblh2, tblg2 )[1], tblg2 );
gap> subdir:= CharacterTableOfIndexTwoSubdirectProduct( tblh1, tblg1,
>         tblh2, tblg2, "D30" );;
gap> IsRecord( TransformingPermutationsCharacterTables( subdir.table,
>         CharacterTable( "Dihedral", 30 ) ) );
true

```

9.2 The Character Table of $(D_{10} \times HN).2 < M$ (June 2008)

The sporadic simple Monster group contains maximal subgroups with the structure $(D_{10} \times HN).2$ (see [CCN⁺85, p. 234]), the factor group modulo D_{10} is the automorphism group $HN.2$ of HN , and the factor group modulo HN is the Frobenius group $5 : 4$ of order 20.

```

gap> tblh1:= CharacterTable( "D10" );;
gap> tblg1:= CharacterTable( "5:4" );;
gap> tblh2:= CharacterTable( "HN" );;
gap> tblg2:= CharacterTable( "HN.2" );;
gap> subdir:= CharacterTableOfIndexTwoSubdirectProduct( tblh1, tblg1,
>
>      tblh2, tblg2, "(D10xHN).2" );;
gap> IsRecord( TransformingPermutationsCharacterTables( subdir.table,
>
>      CharacterTable( "(D10xHN).2" ) ) );
true
gap> m:= CharacterTable( "M" );;
gap> fus:= PossibleClassFusions( subdir.table, m );;
gap> Length( fus );
16
gap> Length( RepresentativesFusions( subdir.table, fus, m ) );
1

```

An alternative construction is the one described in Section 3.1, as $(D_{10} \times HN).2 = M.G.A$ with $G = 2 \times HN$, $M.G = D_{10} \times HN$, and $G.A$ the subdirect product of $HN.2$ and a cyclic group of order four (which can be constructed as the isoclinic variant of $2 \times HN.2$, see Section 2.4).

Here is this construction:

```

gap> c2:= CharacterTable( "C2" );;
gap> hn:= CharacterTable( "HN" );;
gap> g:= c2 * hn;;
gap> d10:= CharacterTable( "D10" );;
gap> mg:= d10 * hn;;
gap> nsg:= ClassPositionsOfNormalSubgroups( mg );
[ [ 1 ], [ 1, 55 .. 109 ], [ 1, 55 .. 163 ], [ 1 .. 54 ], [ 1 .. 162 ],
  [ 1 .. 216 ] ]
gap> SizesConjugacyClasses( mg ){ nsg[2] };
[ 1, 2, 2 ]
gap> g:= mg / nsg[2];
CharacterTable( "D10xHN/[ 1, 55, 109 ]" )
gap> help:= c2 * CharacterTable( "HN.2" );
CharacterTable( "C2xHN.2" )
gap> ga:= CharacterTableIsoclinic( help );
CharacterTable( "Isoclinic(C2xHN.2)" )
gap> gfusga:= PossibleClassFusions( g, ga );
[ [ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 11, 12, 13, 14, 15, 16, 17, 18, 19,
  20, 21, 22, 23, 23, 24, 25, 25, 26, 27, 28, 29, 30, 31, 32, 32, 33, 33,
  34, 35, 36, 37, 37, 38, 39, 40, 40, 41, 42, 42, 43, 43, 44, 44, 79, 80,
  81, 82, 83, 84, 85, 86, 87, 88, 89, 89, 90, 91, 92, 93, 94, 95, 96, 97,
  98, 99, 100, 101, 101, 102, 103, 103, 104, 105, 106, 107, 108, 109,
  110, 110, 111, 111, 112, 113, 114, 115, 115, 116, 117, 118, 118, 119,
  120, 120, 121, 121, 122, 122 ],
  [ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 11, 12, 13, 14, 15, 16, 17, 18, 19,
  20, 21, 22, 23, 23, 24, 25, 25, 26, 27, 28, 29, 30, 31, 32, 32, 33, 33,
  35, 34, 36, 37, 37, 38, 39, 40, 40, 41, 42, 42, 43, 43, 44, 44, 79, 80,
  81, 82, 83, 84, 85, 86, 87, 88, 89, 89, 90, 91, 92, 93, 94, 95, 96, 97,
  98, 99, 100, 101, 101, 102, 103, 103, 104, 105, 106, 107, 108, 109,
  110, 110, 111, 111, 113, 112, 114, 115, 115, 116, 117, 118, 118, 119,
  120, 120, 121, 121, 122, 122 ] ]
gap> StoreFusion( g, gfusga[1], ga );
gap> acts:= PossibleActionsForTypeMGA( mg, g, ga );;

```

```

gap> Length( acts );
1
gap> poss:= PossibleCharacterTablesOfTypeMGA( mg, g, ga, acts[1],
>      "(D10xHN).2" );;
gap> Length( poss );
1
gap> IsRecord( TransformingPermutationsCharacterTables( poss[1].table,
>      CharacterTable( "(D10xHN).2" ) ) );
true

```

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