RADIATION STUDIES OF ARYL GLYCOSIDES

PART IV. FIELD-IONIZATION, MASS SPECTROMETRY OF ARYL GLYCOSIDES

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ABSTRACT

Field-ionization, mass spectrometry of aryl glucosides leads to cleavage and rearrangement reactions at the glycosidic bond. Cleavage gives the ion *m/e* 163 derived from the sugar moiety, and rearrangement gives an ion from the aglycon *m/e* $(M-162)$. The extent of the two individual processes, when the substituents are varied in the aglycon, have been correlated by using the Hammett relationship $\log Z/Z_0 = \rho\sigma$, to give ρ +0.68 for rearrangement and ρ +2.0 for cleavage. The introduction of the aryl aglycon protects the sugar moiety during mass-spectral fragmentation in the manner also shown by these groups during γ-irradiation.

INTRODUCTION

Glycosidic scission following γ-irradiation of crystalline aryl glycosides[1] is due to ionization and excitation processes arising from interaction with the high-energy radiation. Here we consider only the result of ionization events during mass spectrometry, since the chemical consequences observed under these conditions and after radiation action could show some similarity. Since most carbohydrates are thermally unstable and involatile, mass-spectral studies have been performed mainly by using such volatile derivatives as methyl ethers, acetates, and alkylidene acetals. A feature[2] of almost all the mass spectra of carbohydrate derivatives studied is the absence of the peak of the molecular ion. It was suggested initially[3] that the ionization of a carbohydrate molecule begins at the glycosidic oxygen atom, but subsequent evidence indicates that the molecular ion is formed by removal of an electron from the ring-oxygen atom. In any event, the lowest ionization potential must be associated with the lactol and glycosidic oxygen atoms[2,4,5].

Field-ionization (FI) mass spectrometry has proved to be a valuable method for studying molecules which show no parent-ion peaks in electron-impact (EI) mass spectra. The FI technique offers a "soft" method of ionization and has been utilised for studying certain unsubstituted carbohydrates. We now describe the FI mass spectra of aryl D-glucosides and, in particular, the effects of substituents in the aryl aglycon on reactions induced at the glycosidic bond. In addition, FI spectra are compared with EI mass spectra of the parent D-glucose.

EXPERIMENTAL

EI spectra were determined on the AEI MS-12 mass spectrometer at the University of Salford. Samples were introduced through a heated inlet-system at 230°, with the monitor current between 100 and 500 μamp. FI spectra were obtained by using an AEI MS-9 mass spectrometer at the B.P. Research Centre, Sunbury; source temperature, 80°; ionizing voltage 11 kvolts (razor-blade emitter with a blade-plate gap of 0.5 mm). The preparation of the glycosides has been described elsewhere[1].

RESULTS AND DISCUSSION

A comparison of the EI and FI mass spectra of D-glucose is given in Fig. 1. Beckey[8] recently recorded these spectra, and our observations support his conclusions that the elimination of water, which is characteristic for EI spectra, occurs also during FI conditions. Since elimination of water is greatly decreased when the sample is physically adsorbed on to FI wire[8], it is possible that such loss of water is mainly a thermal process. There is general agreement between our FI spectra and that given by Beckey[8], but we find greatly enhanced peaks at *m/e* 60 and 61, which are also abundant in EI spectra. Moreover, contrary to Beckey's findings, the peak (*m/e* 121)

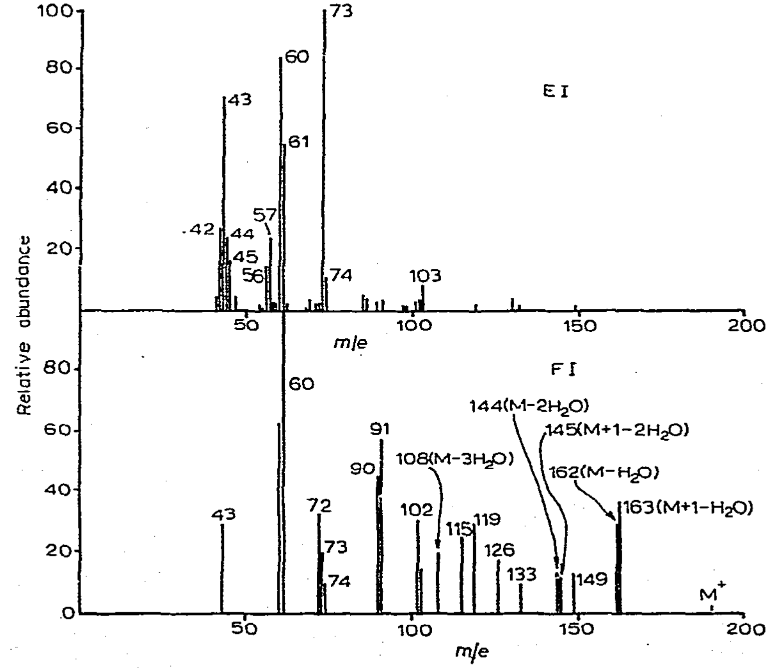


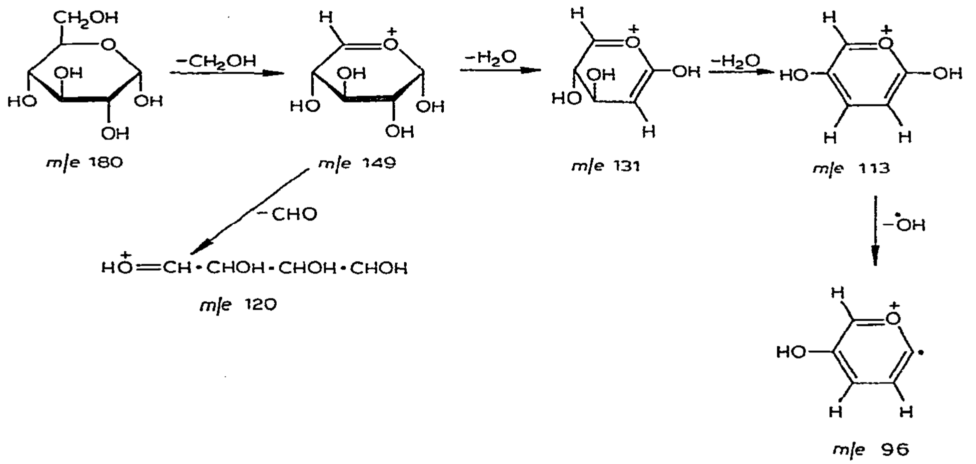
Fig. 1. A comparison of the electron-impact (EI) and field-ionisation (FI) mass spectra of D-glucose.

due to (M+1) $-C_2H_4O_2$ is completely absent in our spectra. The metastable transitions recorded (Table I) during EI conditions enable us to propose that the fragmentation in Scheme 1 is solely due to electron impact. Observation of metastable peaks corresponding to these processes enables the elimination of the possibility that these species arise by thermal or other processes.

TABLE I

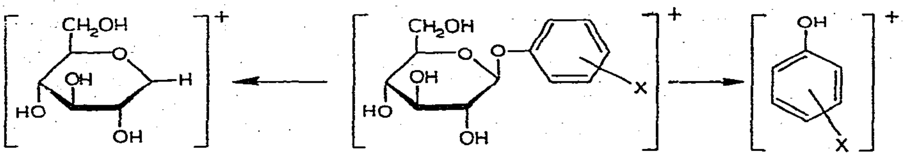
METASTABLE TRANSITIONS OBSERVED DURING THE ELECTRON-IMPACT FRAGMENTATION OF D-GLUCOSE

Metastable (*m/e*)	115.17	110	99.4	96.6	
Probable process	$149^{+} \rightarrow 131^{+}$	$144^{+\cdot} \rightarrow 126^{+\cdot}$	$133^{+} \rightarrow 115^{+}$	$149^{+} \rightarrow 120^{+\cdot}$	
Metastable (*m/e*)	85.8	81.5	80.5	77.5	
Probable process	$119^{+} \rightarrow 101^{+}$	$113^{+} \rightarrow 96^{+\cdot}$	$112^{+\cdot} \rightarrow 95^{+}$	$109^{+\cdot} \rightarrow 92^{+}$ (or $111^{+\cdot} \rightarrow 93^{+\cdot}$)	
Metastable (*m/e*)	74.2	71.4	70.4	58.4	57
Probable process	$107^{+} \rightarrow 89^{+}$	$104^{+\cdot} \rightarrow 86^{+\cdot}$	$103^{+} \rightarrow 85^{+}$	$89^{+} \rightarrow 72^{+\cdot}$	$90^{+} \rightarrow 72^{+\cdot}$



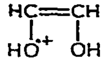
Scheme 1. Possible fragmentation mechanisms of D-glucose under electron-impact conditions (only fragmentations for which metastable transitions are observed are included).

A significant feature of our results is that, when the aryl aglycon is introduced, the spectra under EI and FI conditions are considerably simplified. Since a molecular ion could always be observed under FI conditions, these conditions have been used to examine the effect of the aryl aglycon on the fragmentation processes. Under FI conditions, the aryl glucosides (**1**) fragment to yield, in addition to the molecular ion and its protonated analogues (M+1, M+2), the ions **2** (rearrangement) and **3** (cleavage) as the major species.

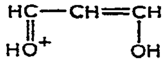


3(163)$^+$ 1 2 (M−162)$^+$

Typical spectra are shown in Fig. 2 for phenyl β-D-glucopyranoside and *o*-nitrophenyl β-D-glucopyranoside, which indicate the variation which is found in the relative proportions of the ions M^+ and ions **2** and **3**. These two glucosides represent extremes of behaviour, but it should be noted that, in each instance, the processes **1**→**2** and **1**→**3** predominate, by far, over any others. Introduction of the aromatic groups significantly protects the molecule from damage, and the extreme fragmentation found for D-glucose is not observed. This behaviour parallels the protection which is afforded by an aryl aglycon during exposure to ionizing irradiation[1,9]. Moreover, the action of ionizing radiations on crystalline aryl D-glucosides yields D-glucose and the corresponding phenol, after dissolution of the irradiated solid in water[1]. The product ions observed during FI mass spectrometry would account for this behaviour and indicate a reasonable analogy between the two processes. When other small peaks can be observed in the spectra, these are characteristic of the mass spectrum of D-glucose. Peaks at *m/e* 73 and 60 were observed, and these predominate also in the mass spectrum of methyl β-D-glucopyranoside, under both EI and FI conditions. Since no metastable peaks corresponding to these transitions have been observed, it is impossible to identify their precursors with any certainty. Labelling experiments, however, indicate that they have the structures **4** and **5**. Such structures could, of


$\underset{\mathrm{HO^{\cdot+}}}{\mathrm{HC}}{=}\underset{\mathrm{OH}}{\mathrm{CH}}$

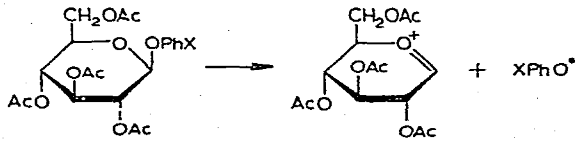
4 *m/e* 60


$\underset{\mathrm{HO^{+}}}{\overset{}{\mathrm{HC}}}\!\!\parallel\!-\!\mathrm{CH}{=}\underset{\mathrm{OH}}{\mathrm{CH}}$

5 *m/e* 73

course, arise from various ions at different stages in the overall fragmentation pathway or merely be the final products of a series of independent reactions.

We are unaware of any mass spectra previously reported for aryl glucosides where the sugar is unsubstituted. Pearl and Darling[10] employed EI spectra to investigate the structures of acetylated, naturally occurring glucosides, and their observations support the previous findings of Biemann[11], on acetylated glucopyranosides, that the major fragment is formed by fission of the aryloxy radical from the molecular ion (**6**→**7**). No indication is given in these studies that the nature of the aglycon influences



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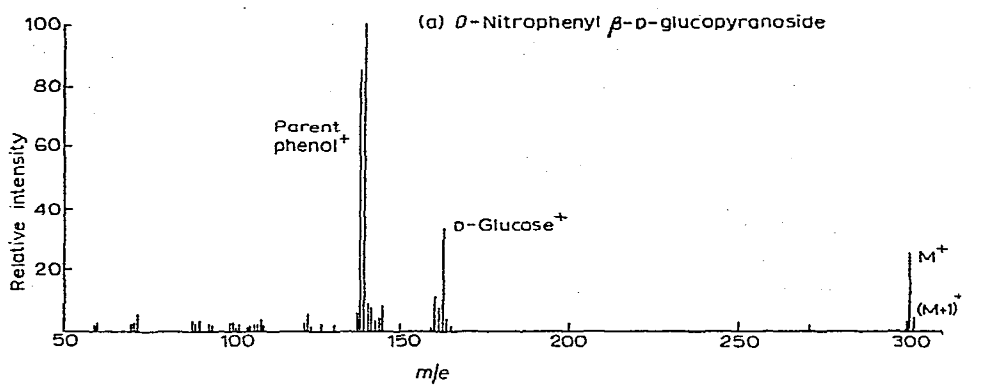

(b) Phenyl β-D-glucopyranoside

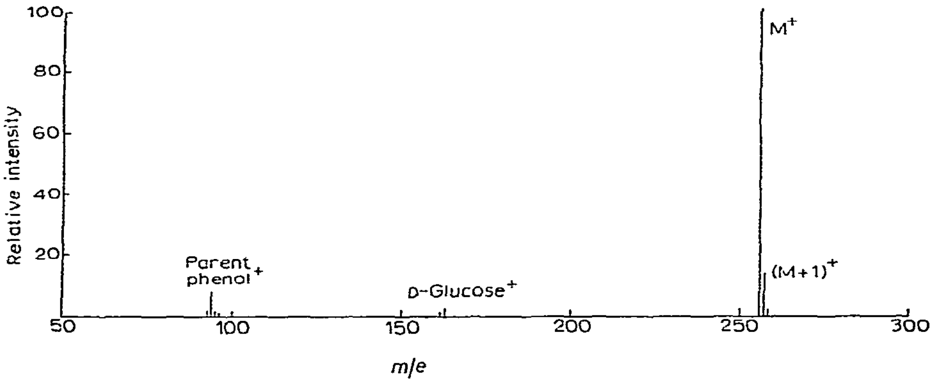

Fig. 2. Field-ionisation mass spectra of (*a*) *o*-nitrophenyl β-D-glucopyranoside and (*b*) phenyl β-D-glucopyranoside.

the extent of this process. We find that the substituent in the aryl group influences the relative proportions of processes **1**→**2** and **1**→**3**. The ions **2** and **3** are also observed during EI conditions, but here it is the rearrangement ion **2** which always predominates. As the ionizing energy is progressively decreased from 70 to 20 eV, the proportion of the rearrangement process increases, which provides another example of a rearrangement reaction that has a lower activation energy than a competing cleavage reaction[12].

The influence of substituents on the intensities of ions **2** and **3** can be rationalised by considering the rates of reactions leading from **1** to **2** and **3**. Using a kinetic approach to mass spectra[13], the ratios $(M-162)^+/M^+$ and $(163)^+/(M)^+$, relative to the identical process in phenyl β-D-glucopyranoside, can be considered to be proportional to the rate constants of processes **1**→**2** and **1**→**3***. Plots of these ratios

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*For process **1**→**2**, $Z/Z_0(Z\ 2) = \{(M-162)^+/M^+\}/\{(M-162)_0^+/(M)_0^+\}$, where the subscript 0 indicates the values for unsubstituted phenyl β-D-glucopyranoside. Similarly, for the process **1**→**3**, $Z/Z_0(Z\ 3) = \{(163)^+/(M)^+\}/\{(163)_0^+/(M)_0^+\}$.

against the appropriate constant in the Hammett equation ($\log Z/Z_0 = \rho\sigma$)[14,15] are reasonably linear for a number of the D-glucosides and are shown in Fig. 3, giving ρ values of +0.7 for the reaction leading to **2**, and +2.0 for the formation of **3**. For the D-glucosides where the Hammett relation is obeyed, it is probable that there is a common route of formation of the ions **2** and **3**. Where nitro groups are present, however, serious discrepancies are found. For this substituent, rearrangement with addition of hydrogen is probable, with the result that the balance between rearrangement and cleavage would be changed. This behaviour has previously been found in both EI mass-spectrometric and photochemical reactions of substituted nitro-aromatic compounds[16].

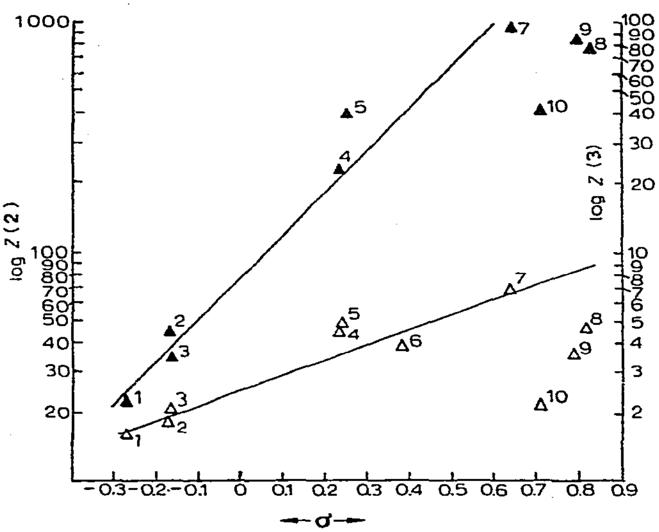
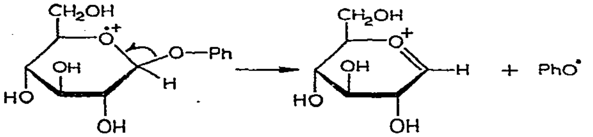


Fig. 3. Correlation of the intensities of the $(X\text{-}C_6H_4OH)^+$ peak (Z **2**) (△ left-hand ordinate) and the 163^+ peak (Z **3**) (▲ right-hand ordinate) with the Hammett σ function. 1, p-OMe; 2, p-CH$_3$; 3, OCH$_3$; 4, p-Cl; 5, p-Br; 6, m-Cl; 7, p-CN; 8, o-NO$_2$; 9, m-NO$_2$; 10, p-NO$_2$.

The mechanism which we favour to account for the results is based on initial ionization occurring in the lactol and glycosidic oxygen atoms[2,17], although ioniza-



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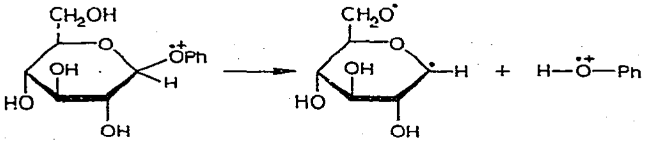

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tion occurring from the low-lying π-orbitals of the aglycon[18] cannot entirely be discounted. On the basis of the former, **1**→**3** may be represented by **8**→**9**, and **1**→**2** by **10**→**11**. Transfer of the hydrogen atom is shown to occur from the primary alcohol group, although, clearly, the transfer could occur with equal facility from other positions in the hexose. The rearrangement reaction (**1**→**2**), which requires hydrogen migration, would not be so greatly influenced as the cleavage reaction (**1**→**3**) by the electron-attracting or -donating character of the substituent and would thereby give the lower ρ-value. Consideration of relative ρ-values could thus assist in deciding between alternative courses in mass-spectral fragmentations.

Finally, in seeking a correlation between mass-spectral processes in the aryl glycosides and their behaviour during γ-irradiation, Fig. 4 shows the relationship between G(radical)[1] and the yield of rearrangement product **2**. Since the radicals on γ-irradiation of aryl glycosides (except when nitro groups are present) are formed by addition of hydrogen atoms to the aglycon, and product **2** is produced by similar transfer of hydrogen atoms, it is not unexpected that there should be a relationship between the two processes.

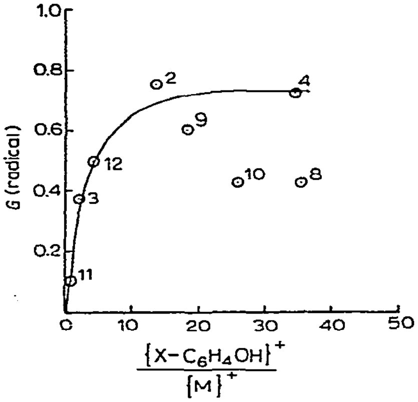

Fig. 4. Correlation of G(radical) with the yield of $(X\text{-}C_6H_4OH)^+$ **2** for a series of substituted phenyl glycosides. Key as in Fig. 3; 11, H; 12, 2,4-dimethyl.

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