The C:O ratio in dark clouds with cyclic star formation

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Observations (Goldsmith et al., 1986) indicate that the gas in dark clouds with embedded low-mass stars experiences a cycle, driven by stellar winds, between low and high density phases. The cycle time is sufficiently short that the chemistry never attains steady state. Icy mantles accumulating on grains during the collapse and dense core phases are thought to be removed in each cycle by low velocity shocks that terminate the low density phase. Models of this type give detailed point-by-point descriptions of both gas and solid phases in molecular clouds (Charnley et al., 1988; Nejad et al., 1990).

In this paper we consider the consequences that follow if mantles are not entirely removed in the shock phase of each cycle. The dark cloud model used includes collapse, ablation and post-shock phases together with an extensive gas phase and surface chemistry of 84 species reacting in about 1200 reactions, with freeze-out of molecules on dust surfaces. We explore computationally several cases, distinguishing especially between those in which chemical differentiation occurs in the desorption process, and those in which all desorption is not selective. Results are presented here for two cases:

A In the shock, 90% of all mantle molecules are retained, and 10% are returned to the gas (non-selective desorption).

B In the shock, 90% of all H_2O mantle molecules are retained, and 10% are returned to the gas, while 100% of all other mantle molecules are returned to the gas (selective desorption).

We show that in the non-selective desorption case (A), the C:O ratio tends to reduce, whereas in the selective desorption case (B) the C:O ratio rises as the number of cycles increases, and the gas may eventually become carbon-rich. The molecular cloud chemistry is then markedly different in the two cases. The results are affected by the cosmic ray ionization rate (see Table I).

The major results of this study are:

1. The C:O ratio in cyclic chemistries is not a given quantity but is determined by the mantle desorption process, the cosmic ray ionization rate, and the cycle number.

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2. The C:O ratio approaches a limit as cycle number increases.
3. Observations of the major species (CO, O, H_2O, C) will enable the C:O ratio to be determined directly, and will lay constraints on the nature of the desorption process.
4. The cycling process may create a carbon rich environment if a selective desorption process operates. If so, the formation of polyynes may be achieved more easily.
5. The behaviour of some species in clump and interclump gas is quite distinct in the two model cases A and B.

TABLE I
The C:O ratio in cyclic models of molecular clouds with (A) non-selective and (B) selective desorption of ice mantles in shocks, for several values of the cosmic ray ionization rate, ζ.

CASE A

Cycle	$\zeta(s^{-1})$ 5×10^{-18}	10^{-17}	10^{-16}
1	0.52	0.55	0.40
2	0.47	0.44	0.29
3	0.57	0.42	0.24
4	0.51	0.42	0.23

CASE B

Cycle	$\zeta(s^{-1})$ 5×10^{-18}	10^{-17}	10^{-16}
1	1.42	1.20	0.66
2	1.77	1.36	0.71
3	1.66	1.30	0.75
4	1.56	1.37	0.79
5	1.49	1.40	0.84
6	1.45		0.87
7	1.43		0.92
8			0.93
9			0.95

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