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30 *A.M. Stuart & A.R. Humphries*

which corresponds to the Hamiltonian $\frac{p^2q^2}{2}$. □

Example The nonlinear Schrodinger equation, (6.2), (1.7) is Hamiltonian with conjugation replacing the transpose and i playing the role of the skew symmetric operator J :

$$u_t = -i\nabla F(u)$$

where

$$F(u) = \int_0^1 \frac{1}{2}|u_x|^2 + \frac{1}{4}|u|^4 dx,$$

and ∇ represents the variational derivative with respect to changes in u, confined to an appropriate function space. □

Two important properties of Hamiltonian systems are described in Result 7.2. In order to explain the result we need to define the following:

Definition 7.1 A mapping $G(U) \in C(\mathbb{R}^{2N}, \mathbb{R}^{2N})$ is said to be *symplectic* if

$$DG(U)^T J DG(U) = J \ \forall U \in \mathbb{R}^{2N}.$$

Here DG denotes the Jacobian of the mapping G with respect to the variable U. We will use an analogous notation for mappings other that G throughout this section.

Result 7.2 *Solutions of* (1.1), (7.3) *satisfy*

(i) $H(u(t)) = H(u(0)) \ \forall t \geq 0$;

(ii) if the solution operator $G(U;t)$ *is defined by* $u(t) = G(u(0);t)$ *for given initial data* $u(0)$ *then* $G(\bullet, t)$ *is a symplectic mapping for each* $t \in \mathcal{R}^+$. □

Proof The first fact follows in a straightforward way since

$$\frac{d}{dt}H(u(t)) = \frac{1}{2}[\nabla H(u)^T u_t + u_t^T \nabla H(u)]$$

$$= \frac{1}{2}[\nabla H(u)^T J \nabla H(u) + \nabla H(u)^T J^T \nabla H(u)] = 0,$$

since $J^T = -J$. The result follows.

For the second part, let $R(t)$ denote $DG(U;t)$, where D denotes the Jacobian with respect to U. Then $R(t)$ satisfies the matrix differential equation

$$R_t = JA(t)R, \quad R(0) = I$$

where $A(t)$ is the Hessian of $H(u)$ evaluated at $u = u(t)$ and is hence symmetric. Now let $V(t) = R^T JR$ and note that $V(0) = J$. Clearly

$$V_t = R_t^T JR + R^T JR_t = R^T AJ^T JR + R^T JJAR.$$

Now, using (7.2) we obtain

$$V_t = R^T AR - R^T AR = 0$$

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