ON OPERATORS ON SEPARABLE BANACH SPACES WITH ARBITRARY PRESCRIBED POINT SPECTRUM

GERHARD K. KALISCH

Abstract. For every compact subset C of $\mathbb{R}$ and every $p$ in $(1, \infty)$ there exists a bounded linear operator acting in a suitable closed subspace of $L_p(0, 1)$ whose spectrum and point spectrum coincide with each other and with C.

The purpose of this note is to exhibit certain separable Banach spaces (including Hilbert space) that admit bounded linear operators with the property that their spectra $\sigma$ are pure point spectra with $\sigma$ any prescribed compact subset of the reals $\mathbb{R}$.

Consider $\mathcal{L}_p(0, 1) = L_p$ with $1 < p < \infty$. Let $(Mf)(x) = xf(x)$ and $(Jf)(x) = \int_0^x f(y) \, dy$ for $f \in L_p$.

Theorem. Let $C$ be a compact subset of $\mathbb{R}$. Then for every $p$ satisfying $1 < p < \infty$ there exists a bounded linear operator $S$ acting in a closed subspace $\mathcal{H}$ of $L_p(0, 1)$ whose spectrum coincides with its point spectrum and equals $C$. The operator $S$ may be chosen to be of the form $xT + \beta$ with $\alpha > 0$ and $\beta$ in $\mathbb{R}$ where $T_1$ is the restriction of $T = M - J$ on $L_p$ to a suitable closed invariant subspace $\mathcal{H}$ of $T$.

Proof. It suffices to show that if $C \subseteq [0, 1)$, then there is an operator $T_1$ as described in the theorem with spectrum $T_1 = \text{point spectrum}$ $T_1 = C$. Let $\mathcal{H}$ be the closed subspace of $L_p$ spanned by $\Phi_\lambda = \{\varphi_\lambda; \lambda \in C\}$ where $T\varphi_\lambda = \lambda \varphi_\lambda$ and $\varphi_\lambda$ is the characteristic function of $[\lambda, 1]$. Clearly $\mathcal{H}$ is invariant under $T$; call $T_1$ its restriction to $\mathcal{H}$. The inclusion $C \subseteq \text{point spectrum}$ $T_1$ being immediate, we shall show that spectrum $T_1 \subseteq C$ or rather complement $C \subseteq \text{resolvent set}$ of $T_1$, which proves the theorem.

Consider first $\mathcal{L}_0$. The formula $(M - J - \zeta)^{-1} = M^{-1} - JM^{-2}$ where $Mf = gf$ shows that $\zeta_0 \in \text{resolvent set}$ of $T$, so $(T - \zeta_0)^{-1}$ is a bounded operator on $L_p$. Let $\mathcal{H}_0$ be the set of all finite linear combinations of the $\varphi_\lambda \in \Phi_\lambda$. We have $(T - \zeta_0)^{-1} \mathcal{H}_0 \subseteq \mathcal{H}_0$ since

\[
(T - \zeta_0)^{-1} \sum \gamma_j \varphi_j = \sum (\lambda_j - \zeta_0)^{-1} \gamma_j \varphi_j
\]

Received by the editors December 4, 1970 and, in revised form, July 20, 1971.

AMS 1970 subject classifications. Primary 47A10; Secondary 46C10, 46E30.

Key words and phrases. Bounded linear operator, $L_p$ spaces, point spectrum.

1 I wish to acknowledge gratefully National Science Foundation Grant GP-21334.
where $g_1 = \varphi_\lambda$. Consider now $k = \lim k_n \in \mathcal{K}$ with $k_n \in \mathcal{K}_0$. We have $(T - \zeta_0)^{-1}k = (T - \zeta_0)^{-1} \lim k_n = \lim (T - \zeta_0)^{-1}k_n \in \mathcal{K}$ so that $(T - \zeta_0)^{-1}\mathcal{K} \subset \mathcal{K}$. It is now an easy matter to check that the restriction of $(T - \zeta_0)^{-1}$ to $\mathcal{K}$ is an inverse of $T_1 - \zeta_0$ so that $\zeta_0 \in$ resolvent set of $T_1$.

If $\zeta_0 \notin C$ but $\zeta_0 \in [0, 1]$ we can still show that $(T_1 - \zeta_0)^{-1}$ exists as a bounded linear operator of $\mathcal{K}$ into itself so that in this case too we have $\zeta_0 \in$ resolvent set of $T_1$. We first observe that if $I$ is an interval in the complement of $C$ in $[0, 1]$, then the functions of $\mathcal{K}$, being limits of linear combinations of characteristic functions of $[\lambda, 1]$ with $\lambda \in C$, are constant on $I$.

Consider then $\zeta_0 \in I = (\lambda_1, \lambda_2) \subset [0, 1]\backslash C$ and calculate $(T - \zeta_0)^{-1}$ on $\mathcal{K}$, as follows: every function $f_0 \in \mathcal{K}$ can be written as $f_0 = f_1 + f_2$ with $f_1 = 0$ on $I$; $f_2 = \gamma I$ where $\gamma$ is the constant value of $f_0$ on $I$. We have

\[(T - \zeta_0)^{-1}f_0 = (T - \zeta_0)^{-1}f_1 + (T - \zeta_0)^{-1}f_2 = g_1 + g_2\]

with

\[g_1(t) = (t - \zeta_0)^{-1}f_1 + \int_0^t \frac{f_1(s)}{(s - \zeta_0)^2} \, ds\]

and

\[g_2(t) = \begin{cases} \frac{-\gamma}{t - \lambda_1} & \text{on } I = (\lambda_1, \lambda_2), \\ \frac{-\gamma(\lambda_2 - \lambda_1)}{(\lambda_2 - \zeta_0)(\zeta_0 - \lambda_1)} & \text{on } [\lambda_2, 1]. \end{cases}\]

This may be seen as follows:

(1) Observe that on $\mathcal{K}$, the operator $T - \zeta_0$ is 1-1; otherwise there would exist a nonzero function $f \in \mathcal{K}$ such that $Tf = \zeta_0f$ but the only functions with this property are multiples of $\varphi_\zeta$ which are not in $\mathcal{K}$ as the functions in $\mathcal{K}$ are constant on each interval in $[0, 1]\backslash C$.

(2) We verify that $(T - \zeta_0)(g_0 + g_1) = f_0 + f_2 = f_0$ by means of a simple calculation. We have \[\|g_1\| \leq M_f \|f\|\] where $M_f$ does not depend on $f_0$ but only on $\zeta_0$ and the $\lambda$'s. Thus $(T - \zeta_0)^{-1}$ is bounded on $\mathcal{K}$. Since

\[(T - \zeta_0)^{-1}g_1 = \frac{1}{\lambda - \zeta_0} g_1 \quad \text{for } \lambda \neq \zeta_0,\]

we have $(T - \zeta_0)^{-1}\mathcal{K}_0 \subset \mathcal{K}_0$ and we conclude as before that $\zeta_0 \notin$ spectrum $T_1$. This concludes the proof of the theorem.

**Department of Mathematics, University of California, Irvine, California 92664**